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PLANTS AND MAN

BASES OF THE STEMS OF THE GIANT BAMBOO (*Dendrocalamus*) in Peradeniya Gardens, Ceylon with a garden coolie standing at their foot

(Photograph by Mr Skene)

PLANTS AND MAN

A Series of Essays relating to the
Botany of Ordinary Life

BY

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PREFACE

THE interest of educated people is naturally enlisted in a subject so intimately related to ordinary life as is the Study of Plants. That interest only requires to be kept alive, or perhaps stimulated. It should not be quenched either by the exposition of what is merely trite and popular, or by presentment in a style that is too technical and abstract.

It had long been the intention of the author to attempt the difficult task of preparing some statement, stripped as far as possible of technicalities, which should nevertheless reflect the current outlook on some of the fundamental features of the Science of Botany. The present aim is to explain, for the general reader, in very general terms, how Plants fabricate for their own life commodities that Man finds so useful in his. The intention is to give a bird's-eye view of these far-reaching processes, though in some instances we shall willingly be led into details : as for example in the case of the green plant-cell, whence ultimately all organised living things draw their food.

Man is both a predatory and a cultivating animal ; and we shall glance both at his ravages on natural vegetation, and at the ingenious ways in which—from his own point of view—he improves the qualities of plants originally wild. But beyond either the scientific or the self-regarding interests mentioned, a

further and peculiar one emerges, when we inquire into those structural devices by which Plants resist the stress of external forces. Not only are these devices curiously intricate and efficient, but Plants have anticipated by untold ages some of the most modern of Man's mechanical inventions. These are different no doubt in material and in structure, though similar in type.

A number of the later chapters are devoted to the conjoint life, so common among Plants, which is promoted by crowding and close contact. Nothing has been more inspiring in the advances of recent years in Biology than the growing insight into the physiological relations that exist between distinct organisms. These relations work out into all the varied grades of mechanical dependence, mutualism, parasitism, disease, death, and decay. These subjects have been broadly treated, rather from the point of view of Plant-Biology than from any other.

It will be rightly guessed from these remarks that the author is not here offering any formal treatise on the innumerable ways in which Man avails himself of the boundless wealth of the Vegetable Kingdom, or suffers attacks from it. But it is hoped that to those who have not time or opportunity for pursuing either topic, the following Essays may open a fascinating field of Nature. In them are sketched certain broad and silent processes of the Plant-World that contribute to Man's every-day convenience, and indeed are essential to his very existence on the earth.

Most of the Essays that are comprised in this volume appeared as a series of articles in *The Glasgow Herald* during the first half of the year 1924. These, but slightly amended and now illustrated by numerous

figures in the text, form the main part of the book. The author wishes to thank the Editor of the *Herald* for permission to collect and issue them in book form. The Essay on " Moor and Mountain " is founded upon a paper contributed to the *Scottish Mountaineering Club Guide*, published in 1921.   That on " Golf-Links and Playing Fields " has been condensed from chapters in *Plant-Life on Land*, published by the Cambridge University Press in 1911.   The permission of the Syndics to use the material and illustrations therein contained is here acknowledged with gratitude.

In the preparation of these Essays the author has been aided by the advice of many friends.   But in particular he desires to acknowledge the help of his brother, Mr. H. M. Bower, who, from the point of view of the interested but non-specialist reader, has by wise suggestion and criticism aided the composition, and protected the general reader at many points against those lapses into technicality that are liable to slip into such a text.

<div align="right">F. O BOWER.</div>

GLASGOW, *October* 1921.

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CHAPTER I

A GENERAL OUTLOOK

When Topsy in *Uncle Tom's Cabin* replies to the inquiry as to her origin, " 'Specs I growed," we smile at her simplicity. But if we pass from the question of the origin of our being to that of the maintenance of the human frame as it moves through the various phases of common life, and inquire into the sources of its food, of its clothing, and of the many accessories of its wellbeing, the thoughtless would be in little better position than Topsy. Even the intelligent and the well-informed might soon find themselves lost in speculation rather than dealing with assured fact. Consider, for instance, an ordinary breakfast table and those who sit at it. They are apt to regard the breadstuffs, butter, tea, cream, and sugar as matters of course. The fish, bacon and eggs, the rice of the kedgeree, the contents of the cruet, the marmalade, honey, and other preserves present no enigma to most people beyond their supply from the dairy, the garden, or the shop. The table linen and even the table itself are hardly thought of by those at breakfast ; while their own clothes, the soap they have so recently used, and the scents that accompany or follow it are equally assumed. The daily paper and the letters

that appear at breakfast are simply the newspaper and the letters.   But the paper that bears the printing, even the very ink itself, the gum that closed the envelopes, and the colouring of the stamps raise interesting and even critical questions of source, preparation, and use.   A mere reference to the shop, the garden, or the farm will not fully satisfy any thinking person.   Without reaching out, as the philosopher may do, to ultimate causes, the inquiring mind will wish to penetrate at least some distance into the gulf which lies between such abstractions and the knowledge possessed by the average man at breakfast.

It requires no high degree of scientific insight to perceive that such articles as those mentioned may all be traced back step by step to one common source. This is the living plant-cell containing that green pigment. chlorophyll, which colours the whole face of the country.   But the chain of events that connect our ordinary supplies with that prime source is often a long one involving many links ;   sometimes, however, the chain is very short and direct.   Moreover, analysis backwards from the article used or consumed towards the source of its supply may reveal the same sort of story in a hundred different forms.   To follow our everyday supplies to their approximate origin may be held as one of the tasks of the Botany of Common Life.   Happily such knowledge is not a condition imposed upon the user ;   but it may increase his interest in his surroundings and alter his estimate of his own position in Nature if he possesses it.

Taking our examples first from ordinary vegetable foods, the cabbage or lettuce afford instances of the shortest possible food-chain ;   for the leaves which we

eat are largely made up of such green plant-cells as carry on the primary constructive process that affords supplies, directly or indirectly, to all living things. In them we devour the very sources of organic material. Here the food-chain exists but as a single link. It is otherwise with the potato, which is a tuber developed underground. The material that feeds it as it grows is not produced directly of its own
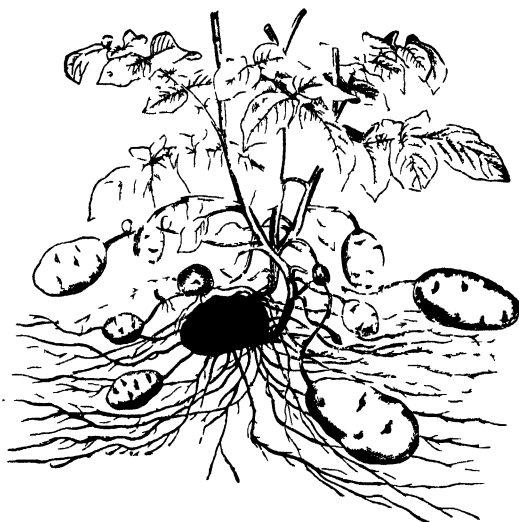
FIG. 1 — LOWER PARTS OF A POTATO PLANT. Above are seen the foliage leaves which carry on nutrition. Below are the swollen tuberous stems, which serve for storage of the material gained by the green leaves above. (After Bullon.)

activity, but by the green leaves of the potato-plant exposed to the sun. It is then passed on to the tuber at second hand for storage. There are thus two links in this chain, though they are but parts of the same plant (Fig. 1). Suppose, however, that the potatoes are used as food for pigs, as is so commonly done, and their substance transmuted into fat; it will then be at third hand that it appears as the breakfast rasher, and the food-chain has three links. The cod-fish that

may have been the basis for our kedgeree suggests a
still longer chain, though the exact links of it are still
imperfectly known.   The cod-fish is a carnivorous
animal.   Zoologists tell us that its food consists chiefly
of small crustacea, that these again feed upon still
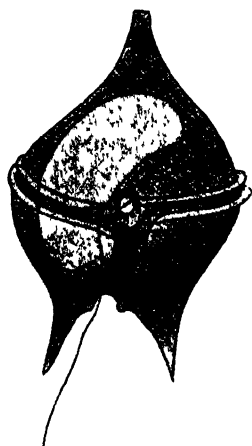smaller crustacea, and that ultimately these find
their food in minute floating
flagellates and radiolarians.
These last bear green or brown-
ish bodies within them, by
means of which they feed
under the influence of the
sun's rays.   Probably the
floating diatoms and dino-
flagellates, which are also self-
nourishing, and are abundant
in ocean-waters, contribute
their share to the food-supply
that ultimately goes to feed the
large cod-fish (Fig. 2).   How-
ever numerous the links in the
food-chain of a cod-fish or of a
herring may be, any adequate
analysis brings us at last to
the minute living cell, green
or brown in colour, floating

FIG. 2 A.—A MICROSCOPIC UNI-
ium)
which
live in salt water, and form a great
part of the ultimate food of fishes.
They are brownish in colour, and
their protoplasm is enclosed in a
membrane formed of numerous
plates.   They are capable of move
ment by means of two flagella,
one of which fits into the hori-
zontal groove, the other is free.
(After Schütt, × 400.)

solitary in water, and exposed to the light.   Such
cells carry on a constructive process which is
essentially the same as that of the green cells of
every blade of grass in the sward of any pasture.
But these unicellular agents are so minute as to be
invisible to the naked eye, and they are so dispersed
that they do not perceptibly colour the water in
which they float.   On the other hand, these pastures

of the sea are of vastly greater area than those of the land, and they provide an ample source of food hitherto imperfectly realised in our modern civilisation, and very insufficiently drawn upon.
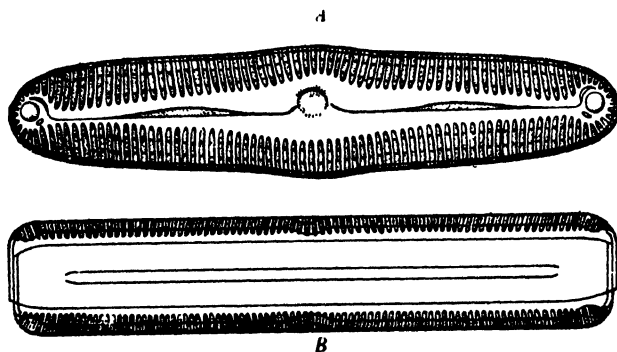

FIG. 2 B.—*Navicula viridis* (Nitzsch) Kütz. An example of the Diatoms, which are unicellular plants of a greenish-brown colour. Most of them live floating in water, and consist of a single protoplast surrounded by two silicified shells which fit together like a pill-box. *A* = view from the top, *B* from the side of the box. They propagate by division, and form a leading feature in the floating plankton of both salt and fresh water. Highly magnified. (After Pfitzer.)

The green cell with its power of construction of new organic material is one of the greatest of all cosmic facts, and Man is bound to reckon with it. Notwithstanding the marvellous increase of his hold on the resources of Nature, he has never yet been able to supersede in the laboratory, as a working and paying proposition, the constructive process carried on in the simplest plant-cell. He does not even yet fully understand what happens there, and it seems improbable that he will ever be able to substitute for the living cell any artificial means of attaining the same end (Fig. 3). The plain fact is that plants can do what animals cannot do : that is, they can increase the sum of their organic substance from inorganic sources. Their supply is drawn, molecule by molecule, from the gases of the

atmosphere, or from water in which they are dissolved.
The material they thus acquire is combustible.   Any
fire of weeds by its combustion restores again to their
simple form the organic substances of the plant-body,
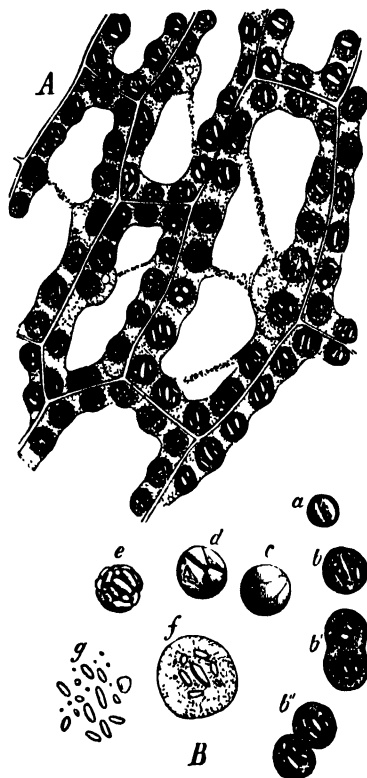
FIG. 3.—CELLS OF THE LEAF OF A MOSS, which carry on nutrition
by means of the green chlorophyll-granules, here darkly shaded.
Many of these are in each cell, embedded in the living protoplasm.
The product of nutrition is starch seen in the granules.   B shows
stages of division of the chlorophyll-granules; f shows the included
starch-grains after the granule has swollen in water.   (After Sachs.)

undoing what had before been done by the plant,
under the influence of the sun, in its green cells.
The process of destruction which we call combustion
is quick, but it represents in its more rapid changes
those transformations which, though more deliber-

ately carried out, form the essence of all non-constructive vital activity. Whether by combustion or by such vital activity, energy is liberated. Liberation of energy is apparent in the heat of combustion, as well as in that of the animal body ; and it may also supply the movement of an engine driven by fuel, or that of a running animal, or of a more slowly moving plant. The prime source of that energy is the same for all, viz. the sun, whose rays falling upon the green cell are absorbed, and their energy stored in the form of chemical separation. That store may be drawn upon and the process reversed either by vital activity or by combustion. The whole gamut of life plays between two extremes. The one lies in those inorganic materials, carbon-dioxide and water, together with certain mineral salts ; these enter the green plant-cell molecule by molecule. The other extreme appears as the organic substance constructed from those materials in that living cell under the direct influence of sunlight. All the remaining phenomena of life are based upon the restoration of the more complex substance thus gained to its original simpler constituents. This restoration is carried out by the most various steps, and without any fixed relation to time. The final result when the material constructed has been passed through the mill of life is again carbon-dioxide and water and certain mineral salts.

This is the rigid framework within which all organic life is compassed. The two kingdoms of living things are both bound by it. but they may interact at many points ; sometimes they even co-operate with mutual advantage, but even then a balance of advantage usually lies with one or the other. At no point is

that interaction more intimate, and more directly under the ken of man than in the story of honey, that most ancient of all sweetmeats, and welcome adjunct of the modern breakfast table. But the human use of it is only a casual, and even an immaterial step in the real romance of honey.

Everyone knows, since Sprengel first described the fact and Darwin expounded it in the light of modern science, that in many types of flower a secretion of nectar secures the visits of insects, and particularly of the bee ; and that the transfer of pollen from the anther to the receptive stigma is the result. The plant being itself rooted in the soil and consequently immobile, the transfer must be effected by some external agent, commonly an animal. That agent is induced to visit the flower by the bait of nectar offered, while its attention to the bait is made more certain by the colour and by the scent of the flower. These attractions all involve sacrifices of substance on the part of the plant. On the other hand, animals are not altruistic ; the bee is simply carrying on the work of the hive, seeking and finding food. Any advantage to the plant is incidental so far as the animal is concerned. But though this is so, a special instance may illustrate the high degree of mutual dependence attained between the plant and the animal. In the Aconite the flower is so constructed as to be pollinated by the humble bee (Fig. 4). It was found many years ago, on tracing the northern limit of distribution of the Aconite and of the humble bee across Northern Europe and Siberia, that the two inhabit almost exactly the same area. We conclude from this that the Aconite is dependent upon humble bees for its pollination, and consequently for its ability to set seed, by means

of which it maintains its race and spreads to fresh stations. On the other hand, humble bees may well be in some degree dependent for their food-supply upon the Aconite, and this is probably a factor in determining their northern distribution. How, then, do such facts as these together fit into the frame-
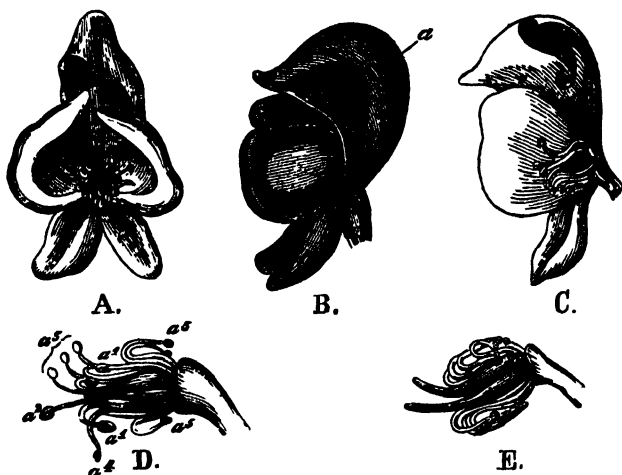

FIG. 4.- FLOWERS OF ACONITE OR MONK'S HOOD. *A*, in the first (male) stage : the erect anthers are coated with pollen *B*, the same flower seen from the side, with a hole (*a*) bitten in the hood for stealing the honey by a short cut. *C*, the same in longitudinal section. *D*, the essential organs in the male stage, showing the anthers becoming successively erect when shedding the pollen, and curving backwards when empty. *E*, the essential organs in the female stage, with the stigmas projecting and receptive (*A-C*, natural size ; *D*, *E*, × 2). (After Muller) Normally the bee perches on the essential organs in order to suck honey from the honey-glands under the hood ; and, as the stamens shed their pollen before the stigmas of the same flower are ready to receive it, pollination from the same flower is improbable, and cross-pollination probable.

work of organic life playing between the constructive process in the green cell and the restitution of the substance so gained to its original sources ?

The bee, like all animals, supports its existence upon food derived directly or indirectly from the physiological activity of green plants. Here it is in the form of the nectar, and probably also of the pollen, supplied by plants such as Aconite. The waste

products of the bee's life are passed off as in other
animals, and part of that food has been physiologically
degraded by its transit through the bee's body.   But
in that process of oxidation energy necessary for the
active life of the animal has been liberated.   The
plant, on the other hand, sacrifices a proportion of
the material gained by its green cells, in the form of
coloured petals, honey, scent, and perhaps a part of
its pollen.   Oxidation accompanies the working up of
material into colour, honey, scent, and pollen ;   but
the plant secures thereby the advantage of pollination.
It is important to realise that the whole incident, in
which the lives of two distinct organisms take part,
involves the use of material gained in the first instance
by the activity of the green cells of the Aconite, and
its partial oxidation in both of them, energy being
liberated to meet the vital requirements of both.

This rather involved example will serve to show how
close may be the interaction of animals and plants in
the down-grade use of organic material.   Man, him-
self, notwithstanding all his complicated relations of
life, must rank with other animals so far as his prime
sources of supply are concerned.   Apart from the con-
structive process in the green cells of plants, which is
essentially one of deoxidation, liberation of energy and
oxidation of substance are at the back of all the other
changes which accompany life.   All may be regarded
as steps towards the resumption of the original in-
organic state of the materials that compose the living
body.   In the ancient world all roads are said to have
led to Rome.   But in our inquiry into the world of
organic life all roads lead to the green cell, which
under the influence of sunlight constructs the com-
bustible material necessary for vital activity.   Its

physiological dominance is not temporary, as was that of Rome in the early history of Europe. It is permanent ; and there is every prospect of its lasting as long as life on this earth continues to be what it is.

CHAPTER II

THE GREEN LEAF

THE green leaf is the familiar organ of nutrition in flowering plants. Everyone knows that under the influence of the sun's rays the leaf is able to acquire fresh supplies of food to meet the demands of the growing plant. It is one thing to admit this to be a true statement of fact, and another to understand how it is done, or to explain in what respects the leaf is an organ singularly well fitted for performing that important function. It is the object of this chapter to explain the essential features of photosynthesis, the process by which the plant itself is nourished under the influence of light. But for this we shall first require some knowledge of the usual structure of the part that carries it out in the higher plants.

The leaf is an organ very variable in size, outline, and texture. Commonly its form is flattened, with a broad blade and a basal stalk. Its usual position is such that it stands out from the stem that bears it, with one of its expanded surfaces directed upwards facing the sky, the other downwards. Since it is really a sun-trap, as we shall see later, the larger the surface thus exposed, the larger will be the sum of the light caught, and of the nutrition gained by it.

But enlargement brings risks of damage by rough winds. This danger is met by the leafstalk being pliable, while the blade is often branched so as to form separate leaflets, and the branching may be repeated
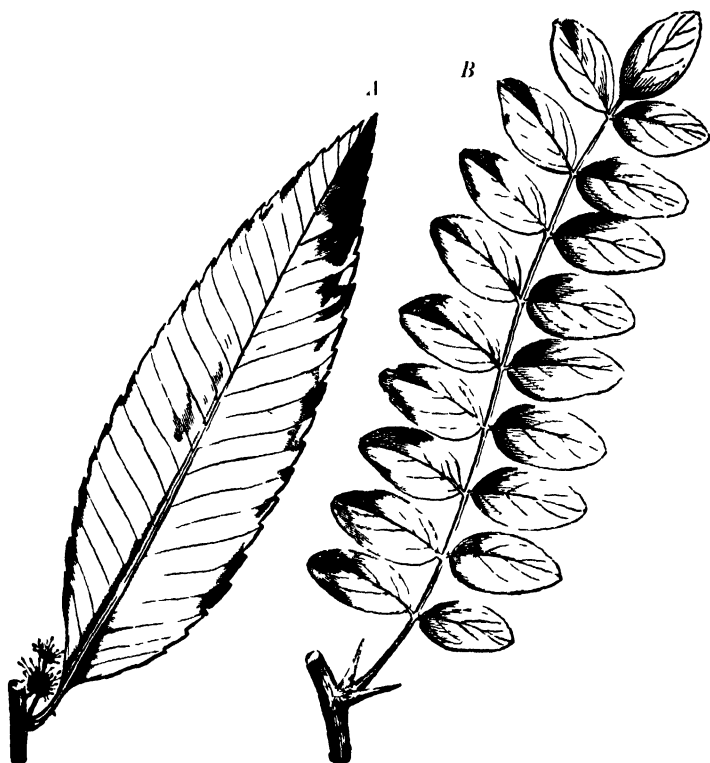

FIG 5 —*A* LEAF OF SWEET CHESTNUT (after Figuier), showing a short leaf-stalk (petiole) and an expanded blade (lamina), with midrib, and primary veins

B—LEAF OF ROBINIA (after Figuier) Here the leaf-stalk is as in *A*, but the blade is pinnate, that is, divided into a row of leaflets (pinnae), one on either side of the midrib

over and over again. Thus a large collective surface may be secured without mechanical risk, and the cumulative effect in nutrition will also be large (Fig. 5 *A*, *B*). The blade itself is often thin, consisting only of a few layers of soft cells ; but it is strengthened by a

branching framework of veins which, like the wooden slats on the sails of a Chinese junk, uphold and flatten out the limp tissue between them. The veins serve also a second purpose in leading upwards the water with salts dissolved in it from the root, and distributing it through the blade, while conversely the food

Fig. 6.—A FLATTENED LATERAL TWIG OF THE LIME, seen from above, showing how its leaves form a compact mosaic (reduced to ⅓)

formed in the blade can be removed by them downwards into the stem. Thus constructed, these thin sheets of living tissue are exposed to air and light, while their mutual arrangement on the shoot is such as to secure that the leaves shall be able to meet the light with the least possible chance of overshadowing one another. They form in fact leaf-mosaics, thus making use of all the space that is available (Fig. 6).

The central point of interest will naturally be the thinner areas of the leaf-blade, in which the actual process of self-nutrition is carried on. Each surface is covered by a skin or epidermis, whose cells are fitted closely together like the tiles of a tessellated pavement, and their outer walls are covered by a thin film of a corky nature, impervious to fluids, called the
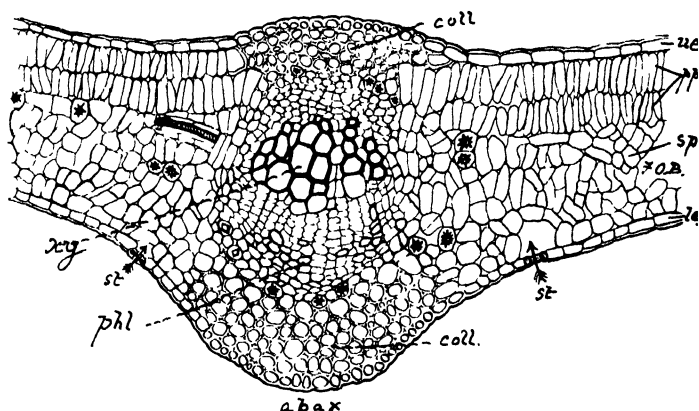

FIG. 7. VERTICAL SECTION THROUGH THE MIDRIB OF A LEAF OF ASPEN, with thinner areas of the blade right and left (× 75). *adax* upper surface; *abax* lower surface; *ue* upper epidermis; *le* lower epidermis, their outer surfaces being covered by delicate cuticle; *pp* palisade parenchyma; *sp* — spongy parenchyma; *coll* collenchyma which strengthens the midrib; *xy* — xylem; *phl* – phloem; *st* stomata on lower surface only. Note numerous crystals of calcium oxalate in certain cells. This figure shows a structure common for leaves of Dicotyledons, as seen in section.

cuticle ; it appears as though laid over the walls like a varnish. The effect of it is to protect the large exposed surface from indiscriminate evaporation of water from within ; but if it were quite continuous it would also have the effect of checking any interchange of gases between the internal cells and the air outside (Fig. 7). Those beautiful organs, the stomata (*st*), save the physiological situation, for sometimes on both surfaces, but more particularly and often even exclusively on the lower, the epidermal skin is punctured

by these minute pores.   They are so small that they
are invisible to the naked eye, and they may be so
numerous that a quarter of a million of them may be
present on a single square inch of surface, though their
number is usually much less than this.   Each is, as the
name stoma implies, like a minute mouth controlled
by two lips, which are the guard-cells, and according
to circumstances they may be, like the animal mouth,
either opened or closed.   When open, as they are by
day, they would allow either water-vapour to escape
or the atmospheric gases to enter.   It will be clear
then that the innerlying tissues are perfectly pro-
tected, both mechanically and physiologically, while
by the action of the stomata the passage of gases
inwards or outwards is under efficient and living
control.

These observations lead us to the internal tissue,
or mesophyll, as it is called.   It is to this tissue
that the full green colour of the leaf is due, for often
the skin is quite colourless, but, being transparent,
the soft green inner tissue shows through (Fig. 8).   It
is composed of numerous sappy cells rather loosely
arranged, with many ventilating passages between
them, but all so closely connected that they form a
continuous sponge.   Those nearer the upper surface
are arranged with some degree of regularity, and with
only small ventilating passages.   They are oblong in
form, with their longer axes parallel to each other, but
vertical to the leaf surface, so that in section they
look rather like an old-fashioned park paling, and are
described as palisade cells (compare Fig. 7, *pp*).   Pass-
ing towards the lower surface this regularity is lost,
and the result is a very porous mass well designated
as the spongy tissue (*sp*).   Its ventilating channels

readily open through the stomata of the lower skin to the outside, and aeration of the internal tissue is thus fully provided for.
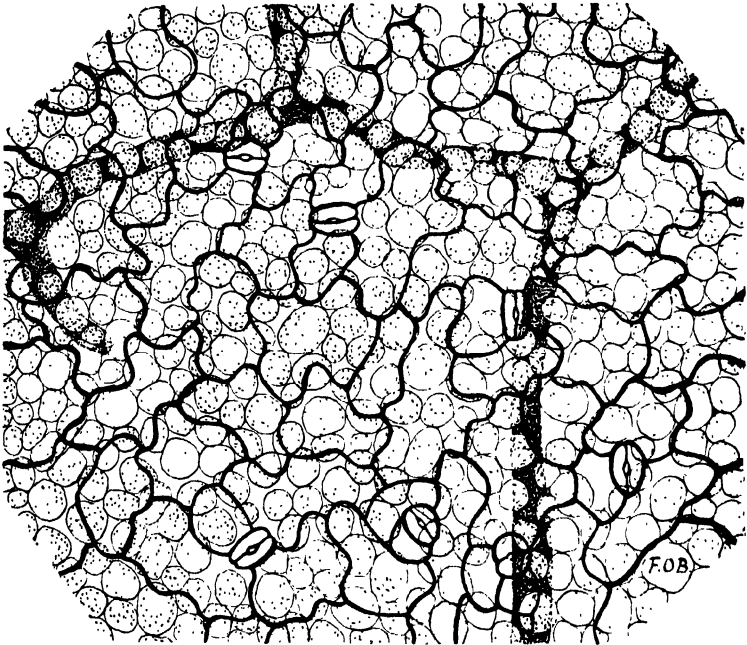

FIG. 8.—A SMALL AREA OF THE SURFACE OF A LEAF OF NASTUR-TIUM (*Tropæolum*), seen as a transparency, in surface view from above. It shows the sinuous outline of the tabular epidermal cells, with stomata, each pair of guard-cells of each controlling a minute pore. Below the transparent epidermis the palisade-cells are seen end-on, and almost circular in outline, with large intercellular spaces between them, especially below the stomata. The veins lie deeper, and are shaded darker. (× 175.)

So far the cells or structural units of the leaf-blade have only been mentioned. The next step will be to describe their features more in detail, for it is within the individual cells that the constructive process goes forward. All the cells of the mesophyll may be engaged in it ; but as they are all alike except for their form, a knowledge of a single palisade cell will suffice

for our purpose. Each such cell consists of a com-
pletely closed sac formed by a thin transparent film
of elastic cell-wall (Fig. 9, comparison may also be
made with Fig. 10, p. 21). During normal life this is
kept tight and tense, like the cover of a pneumatic
tyre, by internal turgor or tension. This tension is
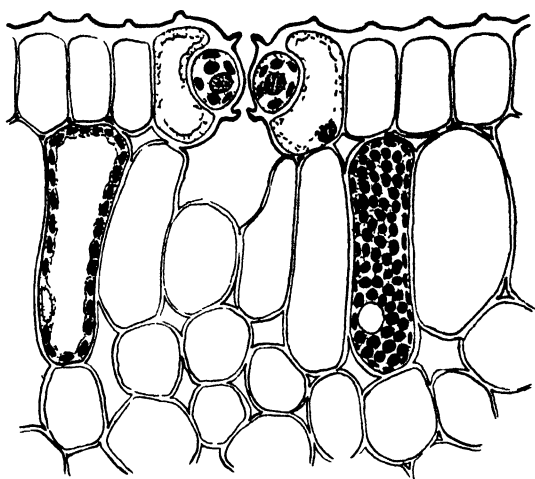exercised by the protoplast, which is the actively

FIG 9 —A SMALL AREA OF VERTICAL SECTION THROUGH A LEAF
OF NARCISSUS (300), representing the epidermis with a stoma
showing its two guard cells enclosing the pore   Below is the meso
phyll, of which two cells are drawn in detail   that to the right is as
seen in surface view from without, that to the left is represented
as in section   The chlorophyll grains are black, the nucleus is
dotted   both are embedded in the protoplasm, which completely
lines the cell wall internally, and surrounds a large central vacuole
Note the intercellular spaces

living body of the cell. This is closely applied as a
thin continuous film of living substance to the inner
surface of the cell-wall, and it surrounds and controls
the cell-sap which fills the cell-cavity. This fluid itself
is clear water with certain substances in solution in it,
and the turgor of the cell is due to the fact that these
substances actively attract water till that attraction is
balanced by the resistance of the stretched elastic wall.
Thus the tension or turgor is due to water-pressure,

and it may be increased or relaxed according to the
condition of the living cell. In some position, usually
embedded laterally in the protoplast, is the nucleus
which dominates the cell functionally. All these parts
are colourless, so that the chlorophyll-grains, which in
normal life are coloured bright green, are thrown into
strong relief. They are present in large numbers in
each cell, appearing under high magnification as minute
vividly green discs packed often very closely in the film
of protoplasm. They usually lie in a single layer so
that their flat sides are parallel to the surface of the
cell-wall. These chlorophyll grains are so small that
they are quite invisible individually to the naked eye ;
but together they give the green appearance to each leaf,
and ultimately to the whole landscape. One hundred
of them would not be an excessive estimate of their
number in a large palisade-cell such as those shown
in Fig. 9. Each leaf may embrace many thousands
of such cells. What, then, may be the estimate of
numbers of these minute green grains on an acre of
ground, or in the landscape we take in with a single
sweep of the eye ? Though individually invisible, it
is these bodies which are the ultimate points of initia-
tion of all physiological supply. They make up by
the vastness of their numbers for their excessive
smallness.

The fact that the chlorophyll-grains are green is
itself fundamental, for it suggests that when sunlight
falls upon them certain rays are absorbed. A spec-
troscopic examination of the green leaf shows that the
absorption bands are chiefly in the red end of the
spectrum, but faint bands lie also in the yellow, and
there are three broad bands at the violet end. There
is thus a supply of energy which enters the grain as

light, and it is held there ; and the rays absorbed are chiefly red and violet.   We must next realise that in normal life each cell is fully supplied with water ; both water soaked up into the substance of the cell-wall and protoplast, and even in the chlorophyll grains themselves, and also actual liquid water filling the cell-cavity.   This water holds in very weak solution certain mineral salts.   Lastly, atmospheric air can gain access to each cell through the stomata which are open during the day, and it may penetrate on-wards through the ventilating channels.   The atmo-sphere consists of a mixture of nitrogen and oxygen, with about three parts in 10,000 of carbon dioxide. This last gas, though present in very small proportion, is thus accessible to the moist walls of the living cells, and through them to the actively living contents of each cell.   These substances –viz. water and carbon dioxide – are the raw materials from which the con-structive process starts.   In addition to their supply two further conditions are necessary for photo-syn-thesis to go on : they are, first, exposure to light of sufficient intensity, which supplies energy in the form of those rays which the grains absorb ; and, secondly, a temperature above a certain minimum.   When these conditions are all fulfilled the stage is ready for the curtain to rise upon the drama of food-formation, or photo-synthesis.

Since the details of this process are still a subject of controversy, we may pass at once to the first result that becomes visible after the action has continued for some time.   It appears in most plants, though not in all, as minute grains of starch, which were not there before, within the chlorophyll grains themselves (Fig. 10).   It is probable that sugar and not starch is really

the first substance formed ; but sugar is soluble and would therefore not be visible in the living cell ; while starch, which is also a carbohydrate, is not soluble. We may recognise the visible grains of starch as a
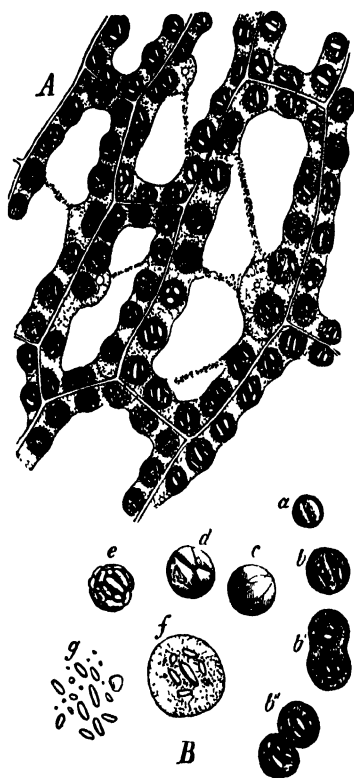

FIG. 10.—CELLS OF THE LEAF OF A MOSS, which carry on nutrition by means of the rounded chlorophyll-granules, here darkly shaded. Many of these are in each cell, embedded in the living protoplasm The product of nutrition is starch seen in the granules. *B* shows stages of division of the chlorophyll-granules ; *f* shows the included starch-grains after the granule has swollen in water. (After Sachs)

convenient insoluble form for storing the results of the constructive process. That process is essentially one of deoxidation, for it can be readily proved that as it proceeds free oxygen is given off. The result as we see is commonly starch, which is a combustible

substance. An expenditure of energy has been needed
to dissociate the stable molecule of the carbon dioxide
used up in the process. It has been shown by more
than one distinct method that the energy of the rays
absorbed by the green chlorophyll is the source of that
energy of chemical separation, which is effective in
promoting photo-synthesis. It is stored in the starch
as energy of chemical separation, but it may be again
made available if the starch be burned.

This is the barest and briefest description of the
fundamental features of this important change. It is
probable that it is essentially the same process which
goes forward in all green cells, even in those tinted
red or brown, as in many seaweeds. In particular this
holds for the floating unicellular plants which form
the first link in those food-chains of the sea mentioned
in the previous chapter. That green flagellate, *Eug-
lena*, which in summer so commonly tints the foul
water of drainage from manure heaps like green pea
soup, nourishes itself in the same way (Fig. 11). It
is possible that the whole body of a flowering plant
has ultimately originated from such free-swimming
cells of green flagellates, encased each in an elastic
wall, as is the resting cyst of *Euglena* (Fig. 11, *D.E.*),
and leading through the steps of upward evolution to
a communal life.

It is well to have some measure of the activity of
photo-synthesis as it proceeds under favourable con-
ditions. It was calculated by Sachs that the amount
of starch formed by a square metre of sunflower leaf
on a summer's day would be about 25 grammes ; but
some later authorities have regarded this estimate as
excessive. In forming 25 grammes of starch the plant
would clear the carbon dioxide from about 50 cubic

metres of atmospheric air, while for each gramme of starch at least 250 c.c. of water of the transpiration-stream would be evaporated. But it is not only the degree of its activity that makes the constructive process in green plants notable ; the point is that this is
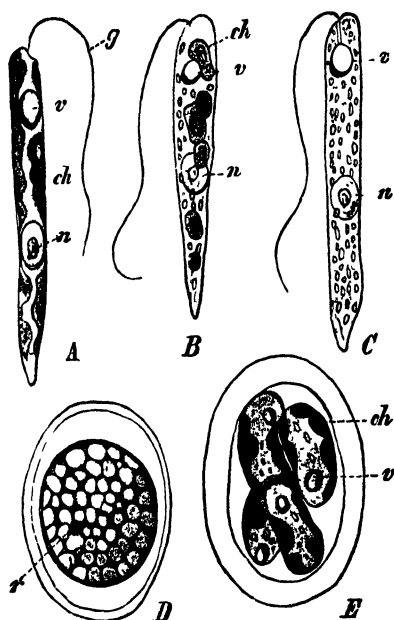

FIG 11.—*Euglena gracilis*, a fresh-water flagellate. *A*, the green motile form, consisting of a naked protoplast, with green chloroplasts (*ch*); *n* nucleus, *v* vacuole and red eye-spot, *g* — flagellum. *B* half-saprophytic form with small green chloroplasts. *C* colourless saprophytic form which lives in nutrient solutions in absence of light. *D* - resting cyst of the form *C*: *r* red eye-spot. *E* —germination of the resting cyst of form *A*, by division into four daughter-cells, which later escape. (After Zumstein. from Strasburger) [*A*, *C*, 630; *B*, × 650; *D*, *E*, × 1000]

the prime source of all organic supply. If this be so, and if the same may be said for the past as for the present, then we are right in regarding the green cell as a great cosmic factor. How great its effect has indirectly been is suggested by the vast masses of limestone rock or of chalk. These may be held to represent the remains of former organic activity, as indeed are

the extensive coral deposits of the present day.   Like
the living coral polyps, the organisms that brought
the limestone into existence must in the past have had
their organic supplies initiated by those green or brown
organisms that formed the earliest links in their food-
chains.   But, turning from such dead accumulations
to the world of things now living, we find as a result of
wide inquiry among these that the chlorophyll-con-
taining cell, whether isolated or leading a corporate
life, is the prime source of the food of all living things.
Hence it must be given its place as the most decisive
organic agent at work upon the earth's surface.

CHAPTER III

THE PLANT BODY AS A WHOLE

IN the simplest green plants all the vital functions, including that of self-nutrition, are carried out in a single cell. But as all large plants consist of many cells, the opportunity was open in the course of the evolution of higher forms for assigning special duties to one or another of them ; and the opportunity has usually been taken. It is only in the simpler of the multicellular plants that all the component cells are green nutritive cells. As a rule one or more cells may serve the purpose of fixing the plant to the substratum, or even of drawing raw material from it, while the rest continue the nutritive duty. But where the plant grows large a need springs up for the conveyance of material from point to point ; a necessity also arises for mechanical strengthening and protection. These needs are commonly met by diversion of other cells from their original duty. Further cells again act as propagative cells ; and so we may understand that the plant has passed in its evolution step by step from the simplest to a more complex state. The primitive plant, like savage man or, indeed, the shipwrecked sailor who is momentarily reduced to elemental conditions, first required food and drink. Protection and

the conveyance of goods from place to place are later
needs that assert themselves after the call for food is
satisfied ; and finally it is only when food is available
that multiplication can take place. Thus we may see
that the first steps in evolution, whether of simple
Plants or of primitive Man, obey the imperative call
for food.

Carrying our comparison forward to civilised Man,
just as the bricks and the steel, worked by the engineer
or the architect into bridges or buildings, bear a certain
price in the market, so the stuff used by the plant in
constructing its own body is also costly. But here
the price is quoted in terms of physiological activity
in the green cell that supplies it. Inorganic substances,
sunlight, and time are necessary for the formation of
organic food. Given these, each individual green cell
can supply itself in the manner described in the last
chapter, and so actively does it do this that it has a
balance standing over beyond its immediate needs.
In a large plant the surplus provides what is necessary
for forming those tissues which are not nutritive. The
roots, the trunk and branches, the scales covering the
winter buds and flowers, as well as the flowers them-
selves, are not green, or only partly so. The origin of
the material composing them has to be accounted for.
Speaking generally these parts cannot make it them-
selves : it is derived from the surplus produced by
the activity of the green cells, mostly in the leaf blade.
If we start from the seed itself, the pea in its pod is
already stored with food gained by the green cells of
the leaves of the parent plant. The materials thus
carried over in storage from the previous year supply
the young seedling on germination till it has formed
its own green leaves, and becomes by their means

physiologically independent. The potato-set acts in the same way till the young plant appears above ground. What happens in the spring in either case is that the substance already stored as starch and other bodies is converted into tissues of new roots, stems, and leaves. Chemical change within the plant-body has taken place, with a certain sacrifice of material, and consequent disengagement of carbon dioxide in respiration ; and from what remains new tissues have been produced that are necessary for the continued and extended activities of the plant. The use of stored material may be delayed, time not being an essential factor in its disposal. What is essential is an available balance of the material gained by photosynthesis, the physiological balance-sheet of the plant being as dependent upon credit and debit as is the banking account of the observer himself.

The vegetative parts of an ordinary land plant have as their prime function that of establishing and maintaining this physiological balance. Those parts consist of the shoot expanded above ground, and coloured generally green ; and the root-system buried in the soil, and colourless. The shoot is composed of a central stem or axis and the leaves which are borne laterally upon it. The features of the shoot may be repeated over and over again in its branches, one of which may arise at the base of each leaf. The stem, so essential for bearing the leaves aloft and exposing each to sunlight with the minimum of risk of overshadowing by others, must needs be more or less elongated, and firm enough to support the weight of the whole shoot against winds from any quarter. For this the upright cylinder is the best shape ; hence most stems are approximately cylindrical and erect.

The stem must be fixed firmly in the soil, not only for reasons of mechanical stability but also to keep up the widest and closest possible communication with the water-reservoir in the soil. A root-system radiating out from the vertical tap-root is the common organ for fixing the plant at its base, while the intimate relation of each rootlet with the soil is secured by an infinite number of delicate root-hairs. These serve the double purpose of mechanical attachment and of access to the water that invests the surfaces of the soil-particles. Roughly speaking, the root-system balances in size the shoot-system seen above ground (Fig. 12).

The softer tissues of any land plant thus constituted are traversed by firmer and more resistant strands, which, like the steel framework of a building of reinforced concrete, act as a strong skeleton, while round it the less resistant tissues are disposed (Fig. 13). The latter may be, and often are, green, and contribute their share to the general nutrition. But the former act as accessories and coadjutors of the green tissues ; without such a skeleton any large green plant would be physically and functionally impossible on dry land. But all such colourless tissues involve an expenditure of material which must justify itself by the assistance given to the corporate whole.

The skeleton or framework does not, however, serve merely the purpose of giving mechanical strength. It also aids by the conveyance of materials from point to point in the plant. The strands composing it consist commonly of three distinct types of tissue. These are fibrous cells, vessels of the wood, and vessels of the bast. The strands are accordingly called fibro-vascular bundles. The fibrous cells are effective for giving strength ; and owing to this property those of the flax

and hemp plants are worked up by man into linen and cordage.   The conduction of materials may be carried
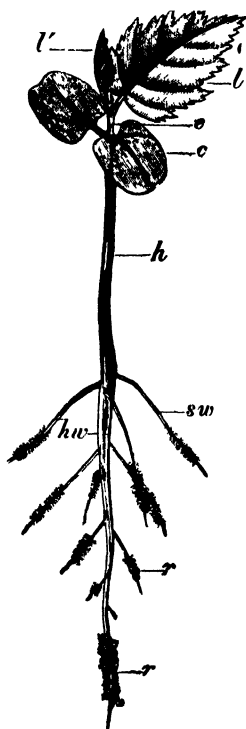

FIG. 12.   FIG. 13.

FIG. 12.—SEEDLING OF THE HORNBEAM, showing the upright stem (*h*) continued downwards into the root and upwards into the shoot. *c* cotyledons; *l*—foliage leaves; *hw* main root ; *sw* lateral root ; *r* root-hairs.   Natural size.   (After Strasburger.)
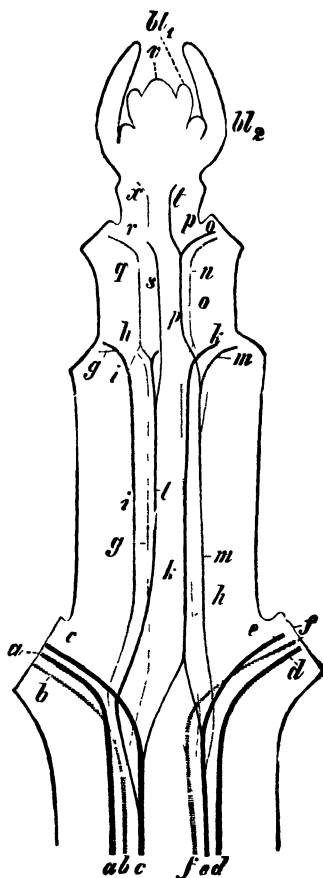
FIG. 13 —END OF A YOUNG TWIG OF CLEMATIS which has been made transparent by removal of the superficial tissues and treatment with caustic potash. The vascular skeleton is thus made evident, but it is in the young state ; each bundle would become stronger with age, and a firm framework would be the result.   (After Naegeli.)

out by the vessels in two more or less distinct and opposing streams of different character.   The vessels

of the wood convey an upward stream of water, with salts in very weak solution absorbed by the roots from the soil below, to make good the loss by evaporation from the leaves. Incidentally this stream conveys those salts to the vein-endings, and deposits them just where they are wanted, that is, in the green cells of the leaf-blade. A downward stream passes through the vessels of the soft bast, which are so constructed that even glutinous colloids may flow through its perforated sieves, carrying down the materials gained by the green leaf to nourish the lower regions of stem and root. The firm resistant wood and the relatively soft bast take almost always a parallel course, together forming the vascular bundles with which the mechanical fibres also are commonly associated (Fig. 14). These tissues together form the skeleton of the plant body, which is clothed by softer tissue. The green cells, which are specially located in the leaf blade, may each be held as a physiological factory in miniature. Each is itself minute, but they exist in millions, and their cumulative effect is accordingly great. The vascular system takes the place of the trade-routes of a country. The raw materials are brought up by the wood, and the manufactured goods are removed by the soft bast for distribution elsewhere ; and just as bricks carted along the roads from the brick-fields are built into the walls of houses at a distance, so the plastic stuff manufactured by the green cells is passed along the vascular strands down the leaf-stalk, and used by the growing cells in distant parts of the plant. Part of it is used in nourishing the protoplasm of the cells, part in thickening the cell-walls to which the mechanical strength of the whole structure is ultimately due.

Let us fix our attention on the trade-route of the raw supply of water with inorganic salts in very weak solution. The wood which is its channel extends from the root-tips through the main roots upwards to the
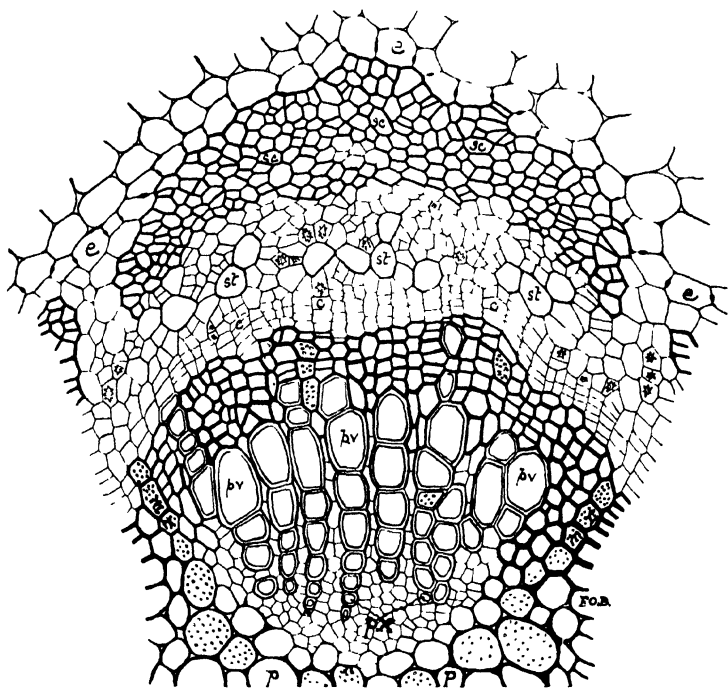

FIG. 11 —TRANSVERSE SECTION OF A SINGLE FIBRO-VASCULAR BUNDLE FROM THE YOUNG STEM OF THE ELM, the top of the figure being nearest to the outer surface. The three constituent parts are shown; externally lies the mass of fibrous tissue (*sc*), but its cell-walls being young are not fully thickened. The sieve-tubes (*st*) are the chief constituents of the bast, with the very thin-walled cells of the cambium (*c*, *c*) at its inner limit. Internally, that is lower down in the figure, is the wedge of thick-walled wood, of which the largest constituents are the pitted vessels (*pr*.). *P* – pith. (× 150)

stem, and onwards to the branches, twigs, and leaves; fine strands of it pass even to the margins and the tip of each leaf. In fact, it is continuous from end to end of the plant. Through its vessels there passes during active life that upward current drawn from the soil

which is often called the transpiration stream. At once the question arises, what makes it move ? There are probably at least two impulses at work. There is first an influence due to the absorptive power of the root-hair. The water absorbed is then forcibly passed upwards through the vessels of the wood. But the agency is not exactly understood, and it is doubtful how far this is effective under the active conditions of the day ; though it is easily demonstrated that it can cause water to flow out at the exposed surface of a stump when the shoot has been cut away. The second factor is probably more efficient, viz. a sucking action from above. It originates in the evaporation of water from the leaves, through the stomata, which is called transpiration. Everyone knows that if a cut shoot be left exposed to the air it withers ; but if the withering has not gone too far the shoot may recover if its cut end be placed in water. The withering is due to transpiration, which is always going on in normal life ; the leaves, especially during the heat of the day when the breathing pores are open, lose water freely by evaporation. What remains of their sap becomes accordingly more condensed. The cells thus depleted absorb water from those below, and it can be shown that they do so with very considerable power. There is thus a suctional influence at work from above which in normal conditions is more potent during the day than the pumping action from below. These two factors may act simultaneously, together urging the upward movement of the transpiration stream through the wood. The water moves in a continuous column under their combined action like a train climbing an incline with a powerful locomotive at its head and a weaker pilot-engine behind. Both engines contribute

to the movement of the train ; but somewhere as you pass from the head of the train the couplings will be seen to slacken. That is where the effect of the pilot-engine from behind begins to be felt, and that point may vary according to the power respectively of the two engines. So it is with the transpiration stream, but the point where the suctional effect from above ceases is normally low down, and during the active period of the day it is somewhere near to the root.

Such facts as these suggest that during life the plant-body, however large or complex, acts as a whole, that the cell-units which build it up live a communal life, and that even when specially developed for a particular function they all contribute to the general well-being. This view is supported by observation of the minute structure of the adult tissues. For it is found that the several units of living protoplasm, or protoplasts of the cells, are connected by infinitesimally thin threads of the same living substance, which traverse the cell-walls, and establish a continuous protoplasmic system that extends from end to end of the plant (Fig. 15). Protoplasm has been described as the physical basis of life. If it be thus continuous from cell to cell the life of the whole plant is one. This view brings the plant-body into line with the animal-body, which it resembles in its power of reception of stimuli and their transmission ; while the reaction to the stimulus in either of them may appear at some point distant from where it is applied.

The most frequent and obvious effect of a stimulus is movement of some kind, which often escapes attention in plants because it is relatively slow as compared with the more rapid movements of animals. But this slowness is a natural consequence of the structure of

plant-tissues.   Each cell is enclosed within a cell-wall,
and this wall, while it protects the protoplast, clogs
movement.   Notwithstanding, such sacrifice of mo-
bility to protection movements do exist in the plant-
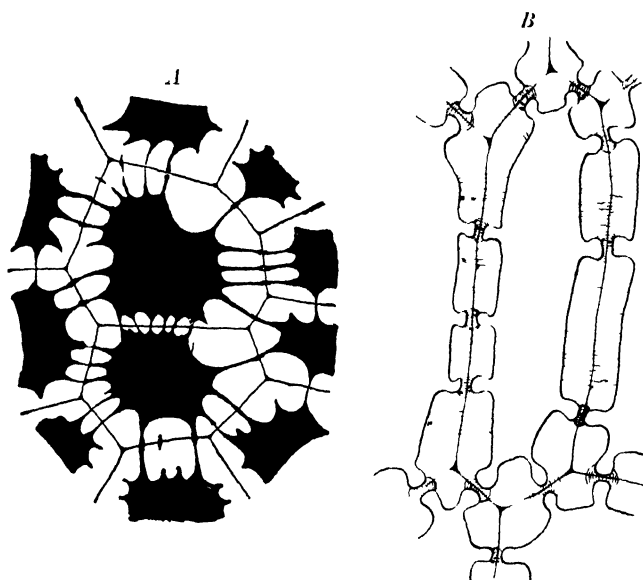body, and they are specially seen in the several parts

FIG. 15. ILLUSTRATIONS OF THE CONTINUITY OF PROTOPLASM
THROUGH THE WALLS OF PLANT CELLS   A cells of the leaf-base
of *Robinia* after treatment with sulphuric acid to swell the walls
and lining of the protoplasm with methyl violet (
cell wall of a single cell of the endosperm of the Double Coconut
showing the threads of the protoplasm traversing both the thick
parts of the wall and the thinner pit-membranes (400) (After
Gardiner)

when young.   Such movements are indeed essential
to its well-being, and they largely determine its adult
form.   But as each part passes over to maturity it
becomes rigid, and apparently motionless, as a conse-
quence of the progressive thickening of the cell-walls.
This, however, does not put a term upon the vitality
of the cells.   The living protoplasts may yet move,
each within its rigid shell, though the part as a whole

would appear to be still. If we speak loosely of plants as " still-life," these words are apt to hide from us a startling and momentous fact. For the cells of a leaf that hangs apparently motionless in the sun may actually be the scene of bustling activity, as shown by the movements of the individual protoplasts enclosed each within its own protecting wall.

CHAPTER IV

THE UNLIMITED SCHEME OF THE PLANT BODY

ALL the higher plants are built up on a scheme that is in itself unlimited. Theoretically any plant by continuing to grow according to that scheme might attain infinite size. This fact is seldom clearly stated by botanists, and it hardly ever occurs to the mind of the ordinary observer. The reason for this omission probably is that the conditions under which plants live impose limits upon the unrestricted realisation of the scheme. Naturally plants growing in water will have the best chance of achieving it to the full, since they are buoyed up by the medium in which they live, and the mechanical difficulties arising from great size are thereby minimised. The giant kelps of the colder seas accordingly provide the best examples ; they include among them the largest plants, and in fact the very largest organisms living on the earth. Plants of *Macrocystis* were estimated by Hooker as attaining a length of 700 feet, and many other kelps attain great dimensions. On land, notwithstanding the greater mechanical risks consequent on growing in the lighter medium of air, certain trees reach a height of over 300 feet ; some are recorded over 400 feet high. A trunk of a giant Red-Wood of California, preserved in

the Natural History Museum, shows a transverse dia-
meter of 16 feet, while its annual rings indicate a
duration of over 1300 years, an age probably far in
excess of that of any kelp. A Kauri Pine is recorded
in New Zealand with a bole 22 feet in diameter at the
base, and it is estimated to be 2000 years old. A con-
tinued thickening of the stem accompanies the growth
in length above, so that the dimensions of the bole
give a rough measure of the head of the tree which it
holds aloft. Such figures as these may impress the
mind as evidence of exceptional success ; but the same
plan as that upon which these giants are built exists
equally in the ordinary plants which meet the eye
in our gardens, or on any country walk. Even
the minute herbs that we tread underfoot bear the
potentiality of unlimited development. There is, in
fact, something different in the fundamental architec-
ture of plants from anything that the higher terms of
the animal kingdom can show.

The essential difference lies in the embryology—
that is, in the genesis of the individual. In the higher
animals a vertebral column appears early in the em-
bryo, and limbs arise with definite number and posi-
tion relatively to it. The scheme of such animals is
laid down once for all, and after the first stages are
past there is no further origination of fresh parts.
Embryology is for them an early phase that is passed
through and definitely closed. But in all plants ex-
cept the simplest of them there is a continued em-
bryology which is not closed, except under the stress
of circumstances.

Certain tissues lying at the tip of the stem and root
remain permanently young (Fig. 16). There the
cells continue to grow and divide. Those below the

extreme tip successively pass over to the adult state, appearing as additions to the already matured parts of the plant. But there is still a residuum of cells of embryonic character at the extreme tip of stem or root, which retain their youth and their unlimited power of growing and dividing. In the shoots of ordinary plants this delicate tissue is hidden away
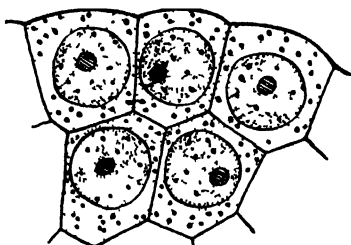

Fig. 16.—Young Cells from the Growing Point of *Tradescantia* which are all alike in having very thin cell walls, and large nuclei each with a highly refractive nucleolus. There are many plastids in the granular protoplasm, here shown as black dots. Such characters are usual in embryonic cells. (× 800.) (After Schimper.)

within the terminal bud, being protected by the successively younger leaves which over-arch it. But any simple dissection of a bud will reveal the increasing delicacy of the tissues as the centre is approached. The actual tip of the stem, or growing point as it is called, is very minute, so that it can only be seen after carefully laying back the younger leaves, or by cutting sections through them ; but yet that growing point is always present at the centre of the normal living bud (Fig. 17). It is true that its activity of growth and cell-division may be intermittent. According to season or circumstance a bud may be dormant, as in the winter, only to recover its activity in the spring. Except for such pauses the activity of an individual stem-tip may be continued indefinitely. The embryonic apex of a giant tree is the lineal descendant

of the original stem-tip of the seedling, and remaining
active after many centuries it may still be able to
produce new leaves in regular succession as of yore.
Thus in plants the formation of limbs or appendages
is not carried out once for all, as in the animal body,
but a long succession of them may be produced on the
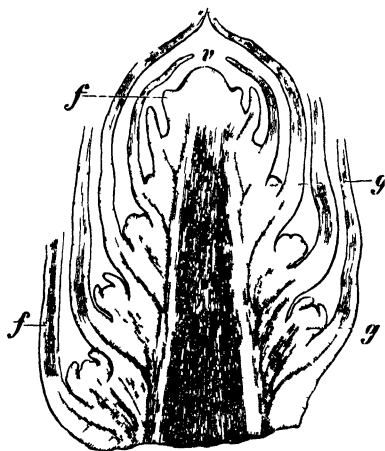indefinitely growing stem.   Similarly. the root may

Fig 17   An Apical Bud cut in Median Longitudinal Section
showing the growing point (*v*) the successive leaves borne laterally
upon it (*ff*) and the rudiments of branches (*gg*) which arise in
the axils of the leaves (10) (After Strasburger)

grow indefinitely, and bear a long succession of root-
lets.   In fact the embryology of the plant is con-
tinued on a scheme without term or limit.
     Here we must note the vast complication involved
in the fact that a new bud is commonly formed at the
base of each leaf, in the angle between leaf and stem
— it is the so-called axillary bud (*gg* Fig. 17).   This
again is endowed with the power of unlimited growth,
and it repeats the characters of the main shoot, deve-
loping into a branch bearing a succession of leaves.
Each of these may again have its own axillary bud.
In this way provision is made for branchings of the

shoot on an endless scale (Fig. 18).   The multiplica-
tion of shoots by this means is upon a geometrical
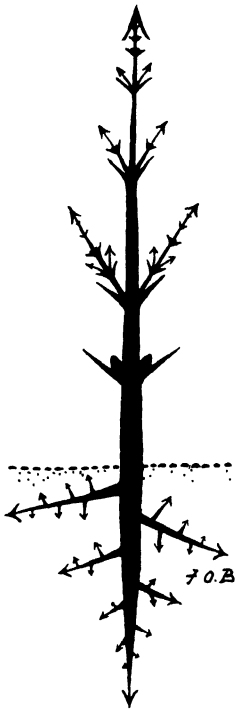ratio, and clearly the development of them all would

FIG. 18 — DIAGRAM suggesting the
plan upon which the unlimited growth
of a Flowering Plant is based.   The
sequence of leaves, and in the axil of
each a bud may arise   The tap-root
may grow indefinitely, and produce a
sequence of lateral roots, and these
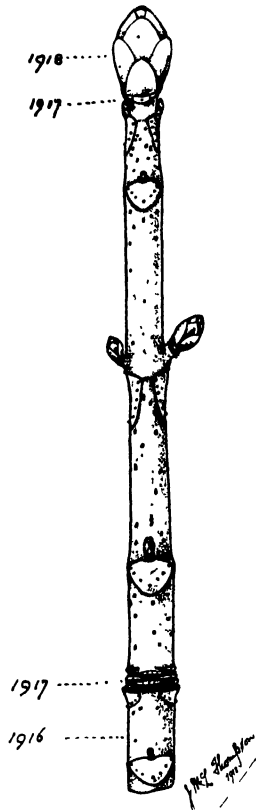also rootlets of higher order

FIG 19.—A TWIG OF HORSE-CHEST
NUT AS SEEN IN WINTER, with scars
where bud-scales and foliage leaves
have fallen away.   Above the scar of
each foliage-leaf is an axillary bud,
but their development is unequal; the
lowest appears to be dormant.   The
annual increments of growth are indi-
cated, that of 1917 lying between the
two limits so numbered.

be a matter of difficulty or, indeed, of impossibility,
as it would lead to hopeless overcrowding.   But the
difficulty does not usually arise, for in most plants a
large number of the buds are arrested early in their

development, and remain dormant (Fig. 19). This apparent over-profusion of branching is not super-fluous : it gives ample provision against the various risks of life. If the main shoot be damaged, one or more branches grow up more strongly and replace it. Foresters know it only too well, for it is this which gives rise in Conifers to many-headed trees wherever the terminal bud has been injured. On the other hand, if a large limb of a tree be torn away the neighbouring branches are already there, and are prepared to fill the breach. Moreover, if the trunk be cut or broken off short, dormant buds may awaken into activity and give the plant a fresh start.

The scheme of construction of the Higher Plants thus outlined is worked out in detail in the most diverse ways. The very different appearance pre-sented by trees, shrubs, and herbs is the result. In some we may see the main stem preserving its identity, and continuously growing more strongly than any of its branches. This gives the pyramidal form seen in the Spruce or " Christmas Tree," or in the young Scots Pine. But the latter loses its pyramidal form as it grows old, owing to the fact that the lateral branches come along more strongly than the leading shoot. This commonly happens, but at an earlier date, in broad-leaved trees and shrubs, giving the bushy habit. An extreme example of the super-session of the main axis is seen in that bizarre plant *Welwitschia*, which grows in South-West Africa. Its main stem is arrested after bearing only two pairs of leaves, the second of which remaining permanent, grow to gigantic size and spread out on the ground, while fruiting branches are formed from the woody crown

between them (Fig. 20). If the germination of this plant had never been seen it would be difficult to tell how the curious adult form had come into existence.
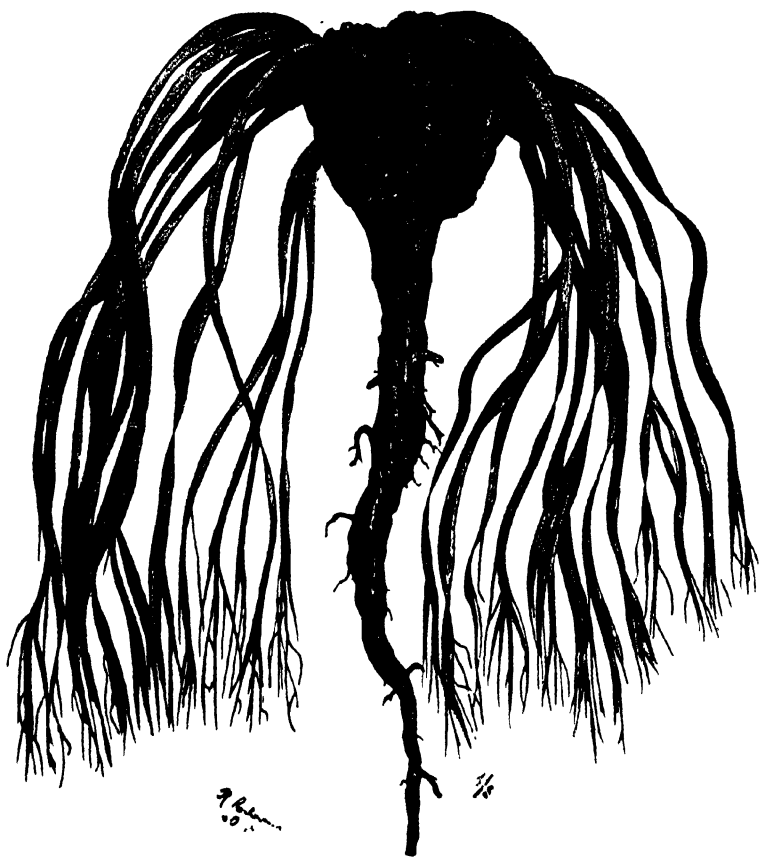

FIG. 20.—ADULT PLANT OF *Welwitschia mirabilis*, one-sixth natural size. (After Schimper.) The massive woody stem in the hypocotyl continuing downwards into the tap-root. The two first plumular leaves persist, and grow to great size, and are torn into ribbons. Between them is a woody crown formed from the two buds in their axils. The main axis is arrested.

In herbs the general habit of the plant is founded upon the same initial scheme as that for shrubs and trees, but the proportions are different and the stature dwarfed. The actual form of such plants is

determined partly by the relative prevalence of the
first shoot, which is usually upright, as in the Sun-
flower or the Broad Bean.   These are both annuals :

FIG 20 *bis* — A CREEPING RHIZOME OF A SEDGE, composed of
several successive shoots (4, 3, 2, 1), the apex of each turning up,
and bearing leaves and flowers   They are all axillary in origin ,
(4) is the oldest, (3) has arisen as a bud in the axil of one of its leaves,
and so on to (2) and (1)   (After Figuier)

that is, plants which run the whole course of their
individual life in a single season ; and such plants are
frequently erect.   It seems probable that the annual

habit made its appearance relatively late in descent,
as a means of catching the favourable periods in
climates marked by strong seasonal change. The
annual survives through the more rigorous periods as
the dormant and resistent seed. But most plants of
the present day, and apparently of the past as well,
live for a succession of seasons, as perennials. The
herbaceous plants now so commonly grown in gardens
are most interesting subjects of study from the point
of view of their general plan, and of their various
methods of taking advantage of the seasons by means
of a stock that persists from year to year. Their
habit is usually creeping, the lateral branches fre-
quently superseding the main shoot (Fig. 20 *bis*).
They may lie exposed upon the surface of the soil, or
more frequently they bury themselves in it, and are
thus protected from the cold of winter or the drought
of summer ; moreover, by their creeping habit prob-
lems of mechanical support are minimised. At fav-
ourable seasons their tips rise above ground as green
leafy shoots, flowering and maturing seeds. But they
die down again in autumn, only to give place next
season to others similarly produced from the perennial
stock. Bulbous plants such as the Narcissus or the
Snowdrop behave in the same way, each bearing the
flowers in spring at the end of an axillary bud, formed
the year before in the axil of a leaf borne by the per-
sistent but dwarfed main axis (Fig. 21, *B, C*). The
Crocus behaves in essentially the same way ; but
there the flower terminates the shoot that bears
the foliage leaves (Fig. 21, *A*). The fact is that a
plant of Narcissus or Snowdrop is constructed on the
same fundamental plan as a Sycamore or an Oak,
which like them bear their flowers on lateral branches.

But in these bulbous plants though the main axis persists it remains very short and is buried in the soil, while each succeeding year an axillary bud arising from it bears the flower which we see above ground.
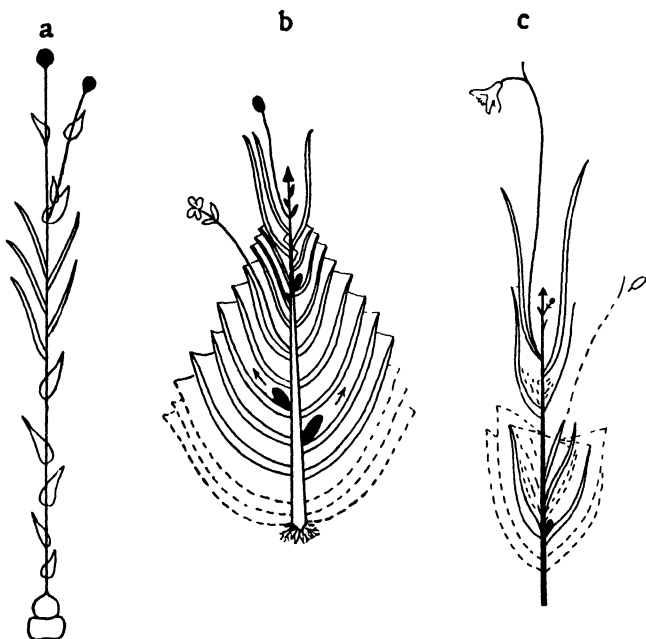

FIG. 21.   *A   Crocus vernus* ; diagram of shoot. A single flower terminates the leafy axis of the current year.   In strong plants a second flower arises laterally.   The flowering shoot itself arises as an axillary bud in the axil of a membranous sheathing leaf of the globular axis of the preceding year.   The succession of shoots is thus sympodial.

B - Narcissus pseudo-narcissus.   A single flower is borne in the axil of the uppermost foliage leaf of the annual flowering shoot.

C - Galanthus nivalis (Snowdrop).   The flower is borne laterally on the flowering shoot which continues indefinitely.   The same is the case in Narcissus.   The whole system is thus monopodial.   (*A, B, C* are schematic drawings, after Church.)

All such arrangements may be looked upon as adaptive to season ; in these plants the cold of winter and the drought of summer are both avoided, for then the perennial stock is safely lodged underground.   These are merely examples of the modifications to which the general scheme is open.   To follow the working out

of the scheme of continued embryology, with its leaf-succession and axillary branching in different types of vegetation, adds greatly to the natural interest of objects that are already familiar in the garden or the country. Doing so tends to impress ever more deeply on the mind the unity, and at the same time the infinite plasticity, of the unlimited plan that underlies them all.

But, it will be asked, if the scheme is itself general and unlimited, why do not all plants attain unlimited size if only they live long enough ? Why are they often so small ? The reply is that there are restrictions imposed upon its full execution, the chief of which is mechanical. Engineers are well aware that there is greater difficulty in building a large structure than a small one. They know that while the weight increases as the cube of the dimensions the strength of the materials increases only as the square. Plants are subject to the same rule. What is possible with a small plant may be mechanically impossible for a large one. In point of fact there is a size-limit, which has been calculated by mathematicians, beyond which trees cannot go as at present constructed. For achieving a larger size there would have to be either a change of the plan of construction or of the material used. Certain trees of over 300 feet have approached the possible limit which their material and plan will allow ; they cannot overstep it, or they would be unable to maintain their form under the weight of the branches and leaves they have to bear. The stem would bend or break. The same principle may apply also to smaller and softer things. When we see a poster showing a gigantic strawberry carried in the arms of a child, or hauled along on a sledge by a team

of horses, we recognise at once that it represents the impossible fancy of an artist in advertisements. Either the succulent strawberry of that size would be unable to keep its form and would collapse of its own weight, or it would require to be constructed like a pumpkin with a hard rind of thickness proportioned to its size. In fact, it would not be a strawberry at all. Thus there are mechanical restrictions upon simple enlargement. A plant exceeds them at its peril. Natural selection steps in and checks it.

Though mechanical demands may thus impose the most drastic and final control over the unlimited development of the plant-body, other circumstances of life act in a similar way. Many buds remain dormant, probably owing to want of sufficient nourishment for all. Want dwarfs plants as well as animals. Seasonal conditions may check or stop apical growth. Frost may kill buds in the tender state in spring, or wind tear away leaves or whole limbs. Animal or fungal attack may destroy many buds or even twigs and branches. But probably the most potent check of all is the physiological drain of flowering. The effects of it are clearly seen in the Lilac, Laburnum, or Horse-chestnut, where the flowering twigs all die. It is particularly effective in perennial herbs, leading to the death of the yearly shoots. In annuals the whole plant appears to be exhausted by the drain of flowering and fruiting, and dies off, leaving only the living seeds. The Talipot Palm is a notable example of such exhaustion on the large scale as regards time and size. This plant grows vegetatively during many years, attaining a height of 40 feet or more : its flowers cover a pyramidal truss some 20 feet high, and after fruiting the whole plant dies (Fig. 22). In these

various ways the theoretically unlimited plan is re-
stricted within bounds.   Each flowering plant we see

FIG 22   A TALIPOT PALM (*Corypha umbraculifera*) in the flowering state

may accordingly be held as the result of a balance
struck between the unlimited potentialities of its

scheme of construction and the limiting conditions, mechanical and physiological, under which that scheme

Fig 22 —b The same Palm after fruiting   The photographs were taken by Mr Skene Ceylon

has been worked out.   But nevertheless the theoretically unlimited scheme underlies the structure of them all, even of the smallest of them.

CHAPTER V

THE FIXED POSITION OF THE PLANT BODY

THE fact that ordinary plants are fixed in the soil and therefore stationary is so familiar that we pay little attention to it, and often remain quite blind to the far-reaching consequences which it entails. The antithesis to ordinary animals is equally a matter of course, and a ready assent is often given to the facile distinction between them, that while plants live, animals live and move. But since Darwin wrote on " The Movements of Plants " the reading public is well aware how far this is from being a valid distinction. Though their motions are slow, young parts of plants do habitually move, tardily changing their form and position ; but as they grow older they stiffen, losing their power of independent movement. Nevertheless, adult parts may still yield to external stresses and strains, such as the pressure of winds or water, just as other elastic bodies might do ; though they execute no spontaneous movements as a whole. Microscopic comparison of the constituent cells in the young and in the adult parts will show that the change from the mobile to the rigid state is due to increasing thickness of the cell-walls which surround and enclose each unit of living protoplasm (Fig. 23).

Each unit may still move within its resistant prison, but the cell so encysted can no longer change its form of its own initiative, nor can the whole organ of which it is a constituent part.   Not only is this so, but as the whole plant is fixed in the soil by its roots, the power of ambulatory movement, which is so large a factor in the well-being of the higher animals, is also
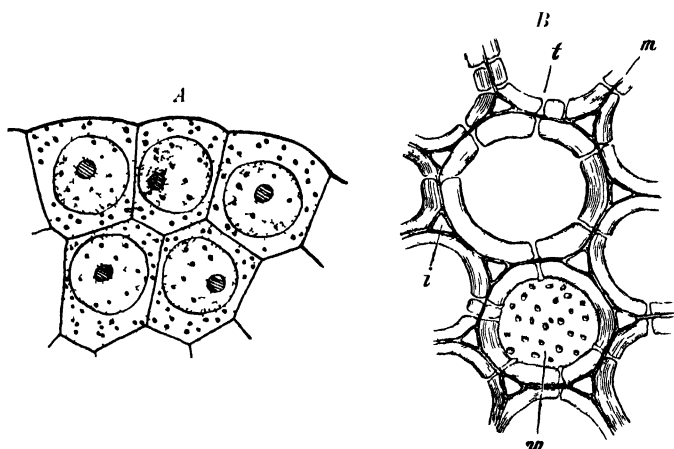

FIG. 23.   A Young embryonic cells with very thin walls, granular protoplasm and large nuclei   (After Schimper)   (800)
B Strongly thickened and pitted cell walls of cells from the mature pith of *Clematis*. M middle lamella   i intercellular space   t pit   u pitted cell wall in surface view   (300)   (After Strasburger)

denied to it.   Thus the adult plant is a fixture as a whole, while the vital movements of its parts are all limited within the rigid containing cell-walls.

The rooted state is clearly efficient for carrying out the nutritive process that is based upon the green photo-synthetic cell, and myriads of such cells are built up into those large and complex individuals that we recognise as herbs, shrubs, and trees.   We have already seen how the acquisition of plant-food is a molecular process, and that it is derived partly from the soil, from which it is conveyed upwards in water

of the transpiration-stream ; partly from the atmosphere. No predatory movement is needed in this quiescent function. Provided the molecules of the necessary materials are themselves mobile, all will be well with the stationary feeding plant. The molecules of the salts in solution in the soil-water, and of carbon dioxide in the air are actually mobile in those media : and it is upon these that the green plant feeds. The antithesis between plants and animals turns primarily upon their nutrition. Animals take their organic supply at second hand, absorbing in some form or another material already elaborated from its inorganic sources, capturing it, and ingesting it often in bulk ; plants draw direct from those inorganic sources, elaborating their food themselves, and absorbing the materials from which it is built up molecule by molecule. For this process their immobile state is a positive advantage ; but the higher animals would inevitably starve if unable to graze or to hunt.

The immobile plant, however, suffers certain disabilities in life as compared with the freely mobile animal. There are difficulties in protection against animal attack, in effecting pollination which is a necessary step to intercrossing, and also in the distribution of the seed when produced. These will severally be considered, and the means explained by which plants survive notwithstanding the difficulties raised by their immobility. The stationary plant is the natural victim of the herbivorous animal, and in many of them, such as ordinary pasture grasses or clover, there are no special means of defence. The caterpillar, the slug, and in tropical countries the leaf-cutting ant, all take their toll, as well as the larger grazing animals, and frequently without any reprisals.

Animals when attacked may escape by wariness and speed, but this is denied to the fixed plant ; its readiest resource is simply to restore as quickly as possible by renewed growth the parts that have been lost. Other means of protection do, however, exist, and are effective. Some plants such as the Spurges and Asclepiads contain distasteful substances in their milky juice ; others such as the Dock, Wood-Sorrel, and some Begonias, are protected by their acid taste; others such as the Rue and Sweet Rush by ethereal oils : others again by sharp needle-shaped crystals embedded in their tissues (Fig. 24). These sharp crystals, which are specially effective against the attacks of snails, are found in many Monocotyledons such as Narcissus or Orchis, and in some Dicotyledons such as the
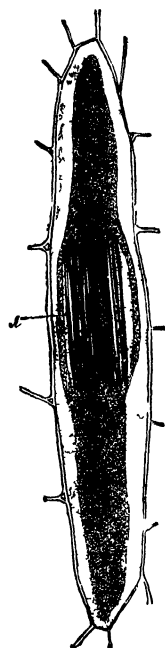

FIG. 24.—CELL OF THE CORTEX of *Dracaena*, much gmnous matter within which is embedded a needle of raphides (r). As the mucilage swells the sharp crystals e disordered, so that their end point in all directions ( ) (After Straasburger)

Vine. They are embedded in mucilage which swells on access of water when the tissues are cut by chewing or biting ; the crystals dislodged, and pointing irregularly in all directions puncture the delicate tissues of the mouth, and make the plant distasteful, protecting it from further attack. In other cases the protection may be external, by pointed hairs, spines, or thorns ; this is particularly so in dry climates, and it is there that the succulent character

of the vegetation offers peculiar attractions to thirsty animals (Fig. 25).

A still more weighty disability following from the fixed position of the plant is the difficulty which it places in the way of pollination, and particularly of intercrossing. We may take it as a general principle
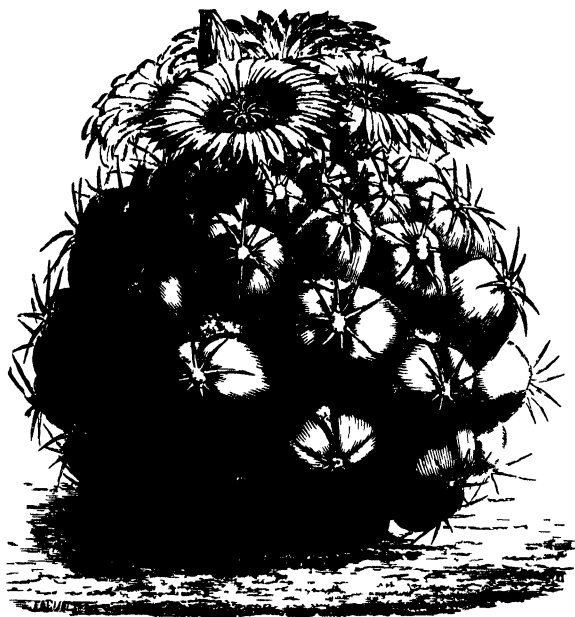

FIG. 25 A SUCCULENT CACTUS IN FULL FLOWER The sappy branches bear each a group of strong spines, radiating outwards like a trophy of bayonets Together they form an effective defence, in a dry country, to the succulent tissues within (After Figuier)

that advantage does accrue from intercrossing. It was the first and most important conclusion drawn by Darwin from his extensive observations on fertilisation in plants, that cross-fertilisation is generally advantageous and self-fertilisation inferior in result. It is easy for the mobile animal to find its mate, and secure this advantage; but where the organism is rooted in the ground that fact seems at once to place

an embargo on intercrossing, unless some mechanical substitute for mobility of the whole organism can be found. This is the real meaning of all those elaborate methods adopted by Flowering Plants for transfer of their pollen. It is this which has brought into existence colours, scents, and nectar, which are so attractive to animals. Unable to effect intercrossing themselves, use is made by plants of other moving agencies, wind, water, or animals. This chapter in plant biology has commanded popular attention more than any other, and has been the subject of much sensational writing. But how seldom is it traced back to its real source, which is the immobility of the plant itself.

It is interesting to inquire into origins in dealing with such facts as these. The seed-bearing plants which show elaborate methods of pollination were certainly evolved from lower, probably from Fern-like plants, and these again from primitive Algæ living in water. In such plants as these the male cells, and sometimes the female also, are capable of independent movement in water ; and if they come, as they very well may, from different parent plants, crossing is easy as a consequence of their own independent power of movement in their native medium, water. The same method will serve also for Ferns and Mosses of to-day, which, as everyone knows, live in damp places, to which indeed they are tied down by the need for external water for their fertilisation. They are, in fact, the amphibians of the vegetable kingdom. But it is otherwise with the higher Flowering Plants, which have adopted a seed-habit and are essentially plants of the land. In these the pollen-grain, from which the male cells are derived, is itself incapable of spontaneous

movement. Even the male cells formed on its germination are immobile. So the problem is quite a different one from that solved so easily by Mosses and Ferns. In seed-plants the pollen-grains must be conveyed bodily from the stamen, where they are produced, to the receptive surface of the stigma. This is the mechanical step which presents the difficulty to these immobile land-plants. That difficulty is the price they pay for the tenure of the best stations on land, or so to speak, the " places in the sun."

The fixed position is then the prime factor leading to those wonderful adaptations of the flower, which have pollination as their end. There is no need to describe these in detail, for they are now the current coin of popular botany. But it may be remarked that fixity of position has probably been a circumstance favouring and so helping to explain the prevalence of the hermaphrodite type in Flowering Plants, that is, the presence of stamens and of carpels in the same flower. This juxtaposition of the organs which produce respectively the male and female sexual cells, makes self-pollination and consequently self-fertilisation possible, and in many cases even probable. There are indeed some flowers that never open at all ; in these self-pollination is virtually a certainty. Such arrangements may be held to be a provision against the risk of pollination failing altogether. A higher degree of certainty of setting seed is attained by these means than would be possible by dependence on external agents. Thus, taking a broad view of the matter, it would appear that it is ultimately the fixed position which has made hermaphroditism more common among the higher terms of the vegetable kingdom than it is among the higher animals.

As a consequence of the transfer of the pollen to the stigma there follow its germination, the putting out of the pollen-tube, and finally the fertilisation of the egg within the ovule by one of the male cells which the pollen-tube conveys.   Each ovule may then ripen into a seed with a germ within.   The number of the seeds is sometimes small, but often it is very large. In some Orchids even millions of seeds may be the crop from a single plant in one season.   How then are these seeds to be distributed so that each germ may have the best possible chance of growing to maturity ? Each requires a position at such distance from its fellows as not to compete with them for light or sustenance ; and this is necessary not only for the maintenance of the race, but also to secure its spread into areas hitherto unoccupied.   Individual movement provides for the distribution of the higher animals, but the higher plants are fixed in the soil as a condition of their nourishment.   Once the germs are rooted in the soil the chance of further spread in this generation is gone.   It need be no matter for surprise to find that in the dissemination of seeds external agents are employed along lines similar to those that are effective in the transfer of the pollen.

The forces of nature, such as the movements of wind and water, are enlisted.   The former easily wafts away light seeds of Orchids or Heaths as it would any impalpable dust, without any special adaptive structure beyond the extreme smallness.   But whole families, such as the Compositæ and the Valerians (Fig. 25 *bis*, *A*), depending on the wind, secure distribution of their nut-like fruits by feathery parachutes ; flocculent hairs may cover the seeds of others, serving the same purpose, as in the Willow

or Cotton (Fig. 25 *bis*, *B*).   Again, tall trees such as
Sycamore, Elm, and Ash develop winged expansions
on their fruits which, acting as sails, are readily caught
by the breeze.   Water-transit is proverbially easy.

FIG. 25 *bis*.—*A*, Fruit of Valerian with feathery parachute   (After Figuier.)
B, Seed of Cotton with tuft of superficial hairs   (After Figuier.)

and by its means such large fruits as the Coco-nut are
carried along the coast ;   in particular the double
Coco-nut of the Seychelles, probably the largest single-
seeded fruit in existence, is known to have floated
across the Indian Ocean.   Sometimes, however, plants
develop means to throw off their seeds mechanically
by sudden release of strained elastic tissue.   The
Broom and Bitter-cress eject their seeds in this
way, while the climax of the method is attained
by the Sand-box tree, the woody fruit of which
explodes with a report like a pistol-shot, and it
scatters its large seeds to a considerable distance
from the parent plant (Fig. 26).   Another curious
method is that involving the principle of the common
squirt ; for the Squirting Cucumber, when its ripe fruit
separates from the stalk, forcibly ejects its seeds em-
bedded in semi-fluid pulp through a basal pore.   Such
devices as these may be held as offsets to the disability
of the fixed position.   But animals are also used as

unconscious agents to the same end.   Seeds and fruits
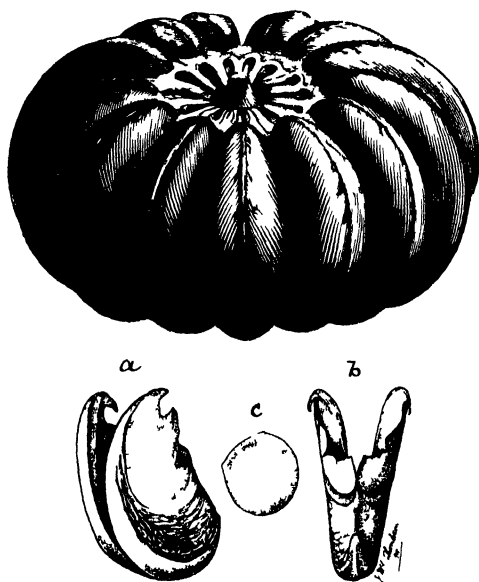may be fixed by barbs and hooks projecting from them

FIG. 26 — The upper figure shows a whole fruit of the Sand box
tree before the rupture of its woody carpels   (After Le Maout
natural size)

a b represent single carpels after the explosion showing each one
split with gaping halves   *c* is a single large seed   The rupture
happens suddenly each carpel taking a wider shape , the carpels
and seeds are thus thrown violently asunder

upon the coat of a passing rabbit or sheep, which will
rid itself of them at some point at a distance from the
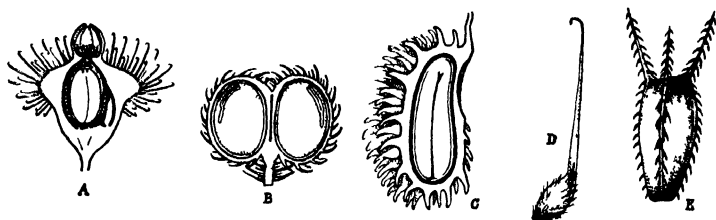
FIG. 26 *bis*   Fruits with hooked outgrowths effective in transfer by
animals   *A*   *Agrimonia B Galium, C = Cynoglossum, D = Geum
E = Bidens*

parent plant (Fig. 26 *bis*).   More commonly still
animals   transport   seeds   internally.   They   are

attracted by the colour, scent, and flavour of pulpy fruits, and eat greedily, swallowing the seeds which, passing through the alimentary canal, are deposited at some distant point. These are merely a few examples of the varied methods by which the germs of plants are distributed. The value of all of them arises from the fixity of position of the parent plant. In most flowering plants wide distribution must be as a seed, or not at all.

Truly in the evolution of the plant kingdom *c'est le premier pas qui coûte.* It was at the very outset that encystment of the green self-nutritive cell was adopted, and this naturally led to basal attachment and a fixed position. The further evolution has consisted very largely in countering by complicated devices the disabilities imposed by those first steps. The wonder of it all is that plants thus stationary have succeeded as well as they have done. Nevertheless that first step was worth while, for it provides efficiently for self-nutrition : incidentally that self-nutrition supplies food also to the rest of the organic world, and ultimately to Man himself.

CHAPTER VI

THE SEASONS

As one looks round on a late spring day upon the bursting buds, opening leaves, and the whole expanse of green landscape bathed in sunshine, one is struck by the vast energy of plant-life developing in its warmth and light. This is the promise of growth increasing throughout the summer, and concentrated in the autumn in fruits, seeds, and tubers. The familiar green colour, cheering to the eye of Man, is justly so : for it is, in fact, the evidence of that wonderful process whereby, as we have already seen, plants feed themselves in the sunlight. Cattle grazing in the field remind one that, in the long run, plants are the only means whereby animal life can be supported. Man himself with all his ingenuity is unable to draw food from any other source than animals or plants. As a general principle, physical life on this earth depends finally upon the radiant energy of the sun, captured by plants by means of that pigment that makes the landscape green.

Let us inquire what is the general distribution of plants throughout the world ? About five-sevenths of the earth's surface is ocean : only about two-sevenths of it is land. The ocean teems with simple

plants, mostly so small as to be invisible to the naked eye. Land plants are, however, more obvious, and we come daily into contact with them, ranging from the lowest forms to the highest. But not the whole of the land is fit for them to grow upon. Parts of it are desert : for instance, the Sahara, the sandy sea-shores, the tops of the highest mountains, and the extreme Polar regions. In the British Islands, where plants encouraged by a temperate climate clothe the earth, we may be apt to forget how much they owe to favourable conditions, and that in places where some necessary condition is not fulfilled plants are absent. In the Sahara the land is too dry. At the Pole or on the highest mountain tops the temperature is habitually too low. But there are large areas of land where all needful conditions are met, and these are covered with living plants. Ordinary land plants fix themselves in the soil by their roots, and draw from it certain parts of their food. But part of their supply is yielded by the atmosphere that surrounds the whole earth. They also need light and warmth, and the radiant source of these is the sun. Water is another need without which everything else fails. Yet land plants owe even their water supply indirectly to the sun, for to his heat is due the circulation of moisture through the atmosphere. Water-vapour rising under his influence from the ocean is condensed in cooler places into cloud and rain. Winds result from the rising of warm air in one region, and the rushing in of cooler air from another to replace it, and thus they act as distributors and moderators of moisture and warmth. The sun then exerts a potent and far-reaching influence on the well-being of plants. The most striking proof of this is the contrast between

winter and summer in the whole aspect of nature ; for the seasons themselves depend on the power and duration of sunshine at any place. When and where, then, do the sun's rays strike the earth ?

The sun is a million times the size of the earth. As he is ninety million miles away, those of his rays that strike the earth's surface are practically parallel to one another. Were that surface flat, and always turned full towards the sun, every point would receive the rays vertically, and the sun would appear constantly to be overhead. But the earth has the rounded surface of a globe, and therefore at any moment there is only one point which can receive the rays quite vertically. From this point, the rounded surface falling away more and more in every direction, the rays can only be received at a sharper and sharper slant, with less and less effect. At any moment only one-half of the earth's surface receives direct sunlight at all, and it thus enjoys the day. The other half is in the darkness of night. But the area that is more or less lighted and warmed is always changing ; for the earth herself is spinning on her axis, with one revolution in every twenty-four hours, giving the regular succession of day and night. She is travelling also in her orbit once round the sun in every year. The earth's polar axis, around which she spins, is inclined to the plane of her orbit at an angle of $66\frac{1}{2}$ degrees—that is, $23\frac{1}{2}$ degrees less than a right angle. Its northern pole points constantly towards a spot near to the Pole Star. Evidently, then, in the course of the earth's annual journey she will, owing to the steady inclination of the axis, expose at one period her northern hemisphere more to the sunshine, at another the southern. Herein consists that constant change in

the lighted and warmed half of the earth which gives
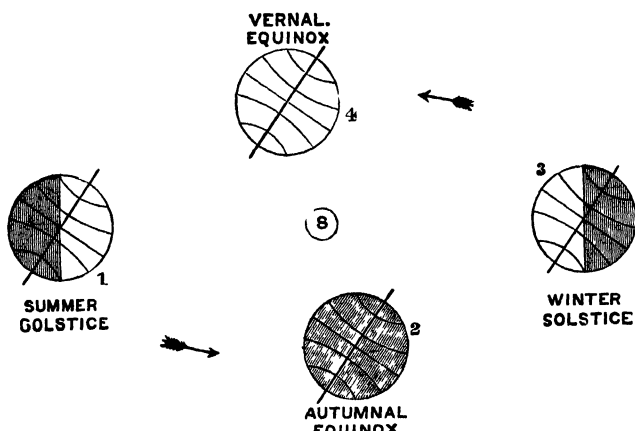the annual succession of the seasons (Fig. 27).

FIG. 27.—DIAGRAM showing the earth's relation to the sun at
different seasons. S - the Sun ; the arrows show the direction of
the earth's movement, and the shading the parts in shadow at the
successive seasons. In particular the south pole will be in shadow
and the north pole fully exposed at the summer solstice (1), while the
south pole will be fully exposed and the north pole in shadow at the
winter solstice (3). (After Huxley.)

Let us quickly follow the four seasons, beginning
with what the calendars call the spring or vernal
equinox, about the 21st of March. On this day the
earth is at that stage in her orbit where her axis is at
right angles to the direction of the sun and his rays.
The illuminated half of her surface extends from pole
to pole. All the places that successively receive ver-
tical rays at noon lie on the equator, midway between
the poles. Every place on the earth's surface has at
this date twelve hours of light and warmth and twelve
hours of darkness, day and night being of equal
length ; hence the name equinox. But while we
speak or think, the earth will be gently entering a part
of her orbit that offers her northern hemisphere more
to the sunshine than the southern. This will be clearly
understood by jumping a quarter of a year to our

mid-summer, near the end of June, which season is called the summer solstice. The North Pole itself is at mid-summer far inside the sunshine area ; the South Pole far outside it. The sunshine area has, in fact, shifted as a whole by $23\frac{1}{2}$ degrees since the equinox ; the rays received vertically at mid-day are at places on the tropic line $23\frac{1}{2}$ degrees north of the equator. Northern regions now get the fullest amount of sunshine that they have at any time of the year, with long days and short nights. Exactly the opposite has happened in the south, where it is mid-winter. But from the summer solstice onwards the northern hemisphere gradually loses its favourable position. Its days shorten, till in September the overhead sun at noon is again on the equator, and we reach the autumn equinox. Thenceforward the southern hemisphere comes more into sunshine than the northern, till at the winter solstice in December the overhead sun at noon is on the southern tropic, with mid-summer in the south and mid-winter in the north. As the earth passes along the fourth quarter of her orbit, the southern hemisphere loses its advantage, and in the following March comes the spring equinox of a new year. Each of the two hemispheres has thus its spring, summer, autumn, and winter, those of the northern hemisphere being half a year apart from those of the southern.

In either hemisphere, from the equator to the pole, there are gradations in the amount of heat and light received from the sun, consequent on the curvature of the surface and the different slants at which the rays are received. For convenience these gradations are grouped into a few natural belts or zones (Fig. 28). The two hemispheres include equal parts of the

tropical, torrid, or hot zone; this is that great equatorial belt between the tropic lines where the overhead sun at noon, never more than $23\frac{1}{2}$ degrees north or south of the equator, exerts very great power, and the length of day and night varies but little. Beyond the tropics there is in each hemisphere a temperate zone, including sub-tropical regions less hot than the torrid zone.
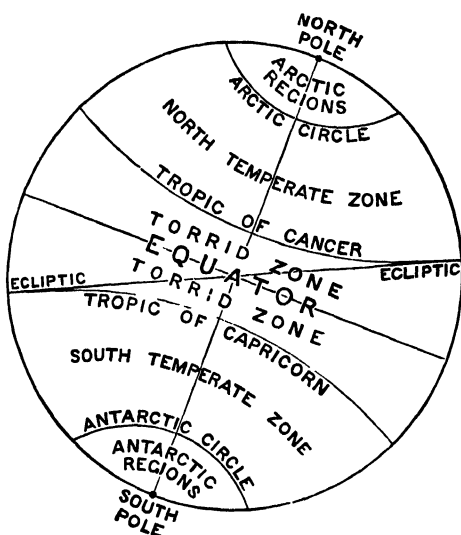

FIG. 25 — The distribution of the surface of the globe into zones
(After Huxley)

From the tropics to the poles the contrast between the seasons and the variation in length of day become gradually more pronounced, till in the frigid zones of the Arctic and Antarctic, around the poles themselves, these differences become extreme, culminating in one long cold mid-summer day and one long colder mid-winter night.

The difference between these seasons may be made clearer to us, as dwellers in a temperate zone, by noting the differences in angle of the sun's rays to the horizon

at mid-day. This naturally varies as the point of observation is further north or south (Fig. 29). If the observer were in London he would find that the angle at mid-day at the winter solstice, that is, on December 22nd, would be 15 degrees ; at the equinox it would be $38\frac{1}{2}$, and at the summer solstice it would be 62 degrees. If the point of observation were further north the angles would be less. For instance, at Kirkwall the angle at noon at the winter solstice would be only $7\frac{1}{2}$ degrees, at the equinox 31, and at the summer
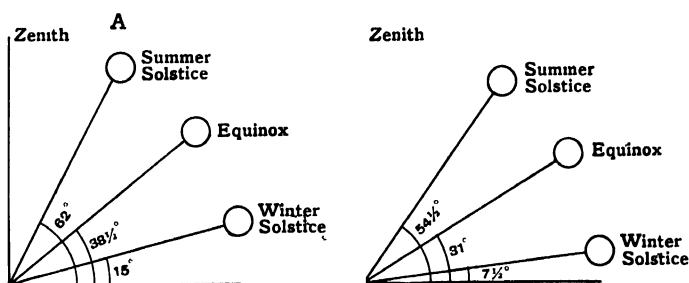
Fig. 29.—*A*, the noon altitude of the sun as seen from London, at the equinoxes and solstices.

B, the noon altitude of the sun as seen from Kirkwall at the equinoxes and solstices. (After Farmer.)

solstice $54\frac{1}{2}$ degrees. It will be seen how far even the largest of these angles, relating to points in the British Islands, falls short of the figure of 90 degrees, which would be that of the overhead sun at noon within the tropics.

The effect of such differences on vegetation is very great indeed, for the intensity of the action of light and heat in nutrition and on the general physiological activity varies with the angle of incidence of the sun's rays. Those rays which strike the green surface vertically, as they mostly would do in the tropics at mid-day, will penetrate more readily than those which strike it obliquely, as in temperate or Arctic zones.

In the latter case much of the light may be reflected from the cell-walls, and would not penetrate into the green cells at all. The same will hold also for the heat-rays. Both of these factors will result in less active chemical change at high latitudes than at lower. On the other hand, the longer period of daily sunshine in summer in northern lands somewhat counteracts this deficiency of intensity of the light and heat as compared with the tropics ; but the comparative shortness of the sunshine in winter accentuates the deficiency. The general result of these factors on vegetation is that the further north you go in the northern hemisphere the more sharply the seasons of summer and winter will be accentuated ; for the greater length of the northern summer day does not compensate for the less intensity of its oblique sunshine. This distinction of seasons culminates in the single long day of the summer solstice and the single long night of the winter solstice in the northern and southern polar lands. Both regions, however, are actually too cold to allow of active vegetation there.

The converse, seen in the more equable seasons of the tropics, is more cheerful to contemplate. They are marked physiologically more by the position of the sun than by the actual length of day and night, which varies little on one side or the other of twelve hours. The nearer or less nearly the incidence of the sun's rays at noon may approach to the vertical, at any spot in the tropics, the greater or less will be its effect upon the vegetation there ; and this has more influence than the comparatively slight variations in the length of day or night. Consequently, if other needs are met, the vegetation is continuously active

there throughout the year, and with greater intensity of life than in the zones further north or south.

Such are the primary conditions afforded by the earth's surface as a dwelling-place for plants. The great differences which its several regions present have an obvious influence on the character of the vegetation. Where light, temperature, and moisture as well as soil, are all favourable, for instance in fertile regions within the tropics, plant-life appears in the form of dense forests and jungles, with undergrowth beneath their shade. The less intense light and the moderate heat of the temperate zones give similar but less profuse results, with summer and winter habits strongly marked. As the conditions, northward or southward, become more rigorous, plants are for the most part smaller and more sparse, till finally the polar lands are practically desert.

But in any place the subtle blend of local conditions, which we call climate, may be more or less kindly to a plant than can be determined by the simple questions, What zone is it in, or What is the season at this moment ? Without the circulation of warmth and moisture land areas would be barren deserts. The ocean gives an endless supply of moisture, which currents of air transfer from it to the land, and the land gives back in rivers. The effects of this circulation vary greatly with the local features and the configuration of the land. Hills and mountain ranges give varied exposure to the sun, and offer shade as well. They affect the force and direction of winds, and the formation of cloud, rain, and river-systems. Sunshine itself varies in its effect with what it falls on, passing more readily through dry air than through cloud or water, and being absorbed by land which is

warmed thereby.   But water is more retentive of heat
than land, which cools quickly ;   therefore a coastal
country like the British Islands, with moderate eleva-
tion and a prevalent south-west wind from the Atlantic,
is milder, cloudier, and more equable than the moun-
tains and dry table-lands of Central Asia, though these
are nearer to the equator.   Moreover, the neighbour-
hood of a continent with an ocean may give rise to a
remarkable regularity of seasonal weather, as in the
monsoons of India and Southern Asia.   Here, the
summer sun heating large tracts of land, the air
ascends, moist air from the ocean drifts in to replace
it, and discharges its vapour in rain, making vast dis-
tricts fertile.   But notwithstanding these and many
other interacting influences on climate in various
places, the great march of the seasons passes inex-
orably over all with transcendent power, warming in
every spring places left cold by winter, helping by
summer's flood of light and heat the growth that
spring began, and ripening in autumn the shoots and
seeds that shall next year wake again into active life.

CHAPTER VII

MEADOW AND PASTURE

IN the 'sixties of the last century, before mowing machines were in general use, the sound of whetstone on scythe-blade in the early morning was a signal that the hay harvest was due. This would fall some time shortly after the summer solstice, the exact date varying according to locality and season. The arrival of the mowers would then conjure up the delights of haytime before the youthful mind, while the seniors would anxiously scan the sky and discuss the weather. Through the fences of the fields put up for hay, and now to be mown, the cattle might be seen at pasture in other fields that had been under hay the year before, for in many districts what is pasture grazed throughout one summer may be meadow put up for hay the next. Thus, meadow and pasture are often merely names applied to grass-land differently treated. Sometimes, however, the term pasture is used only for grass-land that is permanently grazed but never mown, while meadow means grass-land from which hay crops are taken year after year ; or, again, the meadow may be only temporary, where grass and clover are sown together, and after a longer or shorter series of crops have been taken they are ploughed up

again. But in any case such names are applied to fields under growths of perennial grasses, forming with some other plants a close sward.

Whether pasture or meadow, this sward consists essentially of a mixture of grasses and leguminous plants, associated with which there may also be other plants very diverse in their character and affinities. The proportions in which these various plants are present depends in the first instance upon soil, climate, and drainage ; but also very greatly upon the way in which the land has been treated, whether mown or grazed, manured or starved, recently sown down from arable or existing as old pasture or meadow, tended or neglected. The same rules of competition and of survival hold in fields under the hands of Man as for lands in which his influence is only slight ; but they work out there less inexorably than where Man is absent altogether. In fact, cultivation may be regarded as only one among other conditions of survival of the plants which are actually seen living upon the ground. This broad view of cultivated grass-land leads the mind naturally on to those lands, such as Alpine meadows, where cultivation is but slight, and Man's influence is chiefly effective in removing as dairy products or as hay what the soil is willing to yield ; or, finally, to such expanses as the open prairies of America.

Schimper remarks how in open nature woodland and grass-land stand opposed to one another like two equally powerful but hostile nations, which in the course of time have repeatedly fought against one another for the dominion of the soil. The area occupied by each has been limited by the conditions, but even a slight change of climate may renew the fight

(Fig. 30). The patenas of the uplands in Ceylon clearly
show the result of such a contest. They appear as
sharply defined park-like openings in the hill-forest,
densely overgrown by coarse grass, chiefly the Lemon-
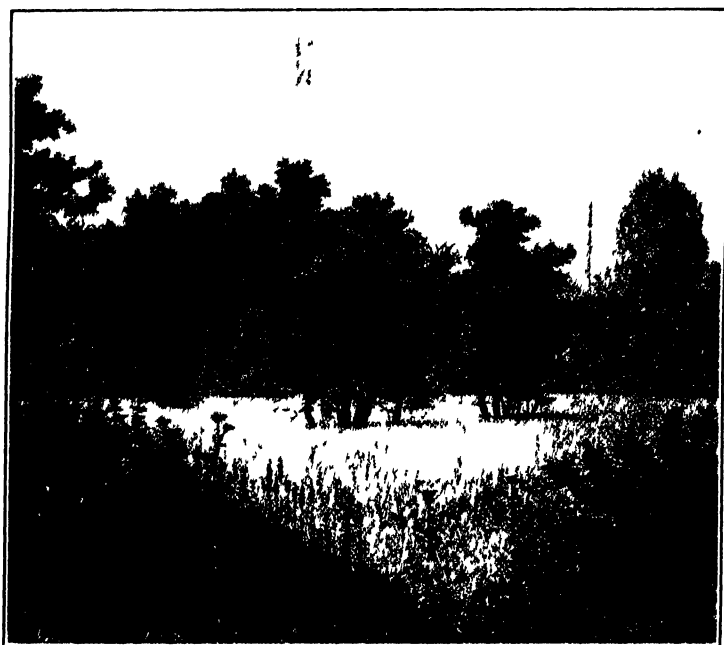grass (*Andropogon*) that yields citronella oil. Only

FIG 30 — A PARK LIKE SCENE ON THE RIVER AWATSCH KAMS
KATKA (After Kittlitz from Schimper) Grass and other low
herbage occupy openings in the woodland

one or two species of trees, and they in stunted speci-
mens, can compete with these densely matted grasses ;
and so exclusive is their sway that the transition from
patena to forest is by a clean cut. This is explained
by the dense growth of the grasses above ground as well
as by the matted web of their roots below. Against
neither of these can seedlings of ordinary broad-
leaved trees compete. The power of exclusion thus

possessed by grasses, and here seen in an extreme form, is the foundation upon which grass-farming is primarily based. At home we may see its effect on any grass-field surrounded by belts of Elm, Beech, Ash, or Syca-more. All of these trees seed profusely. But when do any of their seedlings advance in the fields beyond the first stages of germination ? They are throttled in infancy by the dense mat of grasses, while grazing and mowing would effectually complete their down-fall, even if they were to escape the fate of competition.

How severe that competition is will be understood by an examination of any square foot of turf cut from a good grass field. The interwoven web of fibrous roots, produced not only from the base of the main stem of each grass plant but in many grasses from each node of the runners or stolons, is difficult enough for the fingers to disentangle or to penetrate. But this is what the delicate root of an intruding seedling would have to encounter. It is the same with the parts above ground. Some grasses grow upright from a simple base, but many of the most successful spread over the ground by creeping stolons which root them-selves at each node, and thus occupy an ever-increas-ing area. In either case upright stems rise for flower-ing in the early summer, and, growing more rapidly than any germinating intruder, they tend to throttle it. These circumstances sufficiently explain that high power of exclusion which grasses so often achieve.

The herbage of ordinary grass-land, though it suc-cessfully keeps woody plants at arm's length, com-monly includes a varying admixture of other plants than grasses. The most important of these are leguminous plants such as Clover, Trefoil, and Vetch-ling. These are not to be held as mere intruders but

as co-operators, for they help to keep the soil in good heart, a fact that requires to be explained. Grasses, which naturally compose the greater part of the crop, are plants which depend entirely upon their own activities for their nutrition. They feed themselves from inorganic sources, their roots drawing salts in solution from the soil, and their green leaves forming carbohydrate from the carbon-dioxide of the air. But for the further manufacture of their proteins a supply of nitrogen is necessary, and they cannot lay hold of the free nitrogen of the air. They require it in the combined form, preferably as nitrate. Normally the soil provides this; but if it is deficient in the soil, farm-yard manure or some artificial dressing meets the difficulty. Many pastures are, however, grazed from year to year without manuring, and yet it appears that the supply of nitrogen is sufficient as testified by the condition of the grass. One chief factor towards

FIG. 31. - ROOTS OF BEAN bearing numerous root-tubercles inhabited by Bacteria. Reduced (After Strasburger.)

this is commonly the presence of leguminous plants, such as Clovers ; they are, indeed, specially sown down with grass seeds when arable is converted into grass-land, because they are known to help the supply of combined nitrogen. They are apt to bear upon their roots swollen tubercles, which are inhabited by

Bacteria that gain their entry through the root-hairs, and by their presence stimulate the tissues of the root to growth and cell-division, thus forming the tubercles. It has been found by culture experiments that the tuberculous plant as a whole can increase its own supply of combined nitrogen (Fig. 31).

The Bacterium is known to be able to use the free nitrogen of the air in the formation of its own proteins, while the Clover or Vetch supplies the necessary carbo-hydrate. Thus the activity of the two together results in an increase of the combined nitrogen of the field as a whole, and of the Clover or Vetch in particular. This may be made available for general nutrition whenever the pasture is grazed off by animals on the field, or by decay of the leguminous plant or its parts. Thus the presence of leguminous plants bearing tubercles will tend to maintain the nitrogenous supply in permanent pastures, for they can do what the grasses themselves cannot do.

A large number of miscellaneous species of flowering plants belonging to other families than those named obtain a footing in grass-land. In some upland fields on light soil they may even preponderate over the grasses themselves, and the exhaustive study of a limited area of such land may provide a searching examination in field botany. The number and the frequency of occurrence of such intruders may vary according to circumstances. Not uncommonly a single species may appear to get the upper hand, as for instance Common Sorrel or the Cow-parsnip, both of which being tall and coarse-growing plants are addi-tions more prominent than useful to the crop. A more welcome visitor is the " rib-grass " (*Plantago lanceolata*), which thickens the undergrowth with its

fleshy and nutritive leaves—so different from its relative, the broad-leaved Plantain (*P. major*), whose rosettes of flat leaves have the jealous habit of pressing aside weaker-growing plants, and so of occupying the ground, especially under the converging traffic near a gate. Still more deleterious are such intruders as Nettles or Rag-wort, though these can readily be kept down by repeated mowing and hand-pulling. It would be tedious to give any catalogue of the various plants, worthless or otherwise but as a rule less welcome than grasses, which stray into meadows and pastures. One word may, however, be devoted to the consequences that follow imperfect drainage of low-lying ground. Where the water-table is near to the surface Rushes and Sedges assume dominance over the more nutritive grasses. But in this, as in other troubles of permanent grass the readiest remedy lies in changing the conditions, in this case by drainage, and so altering the balance of competition. This is not only more effective than any manipulation by hand, but it has also a more lasting effect. For in point of fact the competition of species that reigns on the open mountainside, or in the wild valley, rules also in the cultivated fields ; and the skilful farmer takes steps, by altering the physical or nutritional conditions, to tip the balance of success in favour of those plants which he wishes to secure as his crop.

There is, however, another class of plants whose effect on the crops is more insidious and difficult to meet or to check. They are not merely competitors for space, but parasites, which weaken their victims by withdrawing nourishment from them. A necessary condition for parasitism is contact, and in the crowded vegetation of any field this is easily secured, either by

the roots in the soil or among the exposed shoots. The common Yellow Rattle, with its pale green shoot, its yellow flowers, and seeding capsules, looks innocent enough ; but if it be carefully dug up its roots are found to be fixed by suckers upon those of the grasses amongst which it grows. It has taken advantage of their contact so that it can draw nourishment from them in addition to what it can manufacture for itself. The stunted growth of the grass bears witness to the
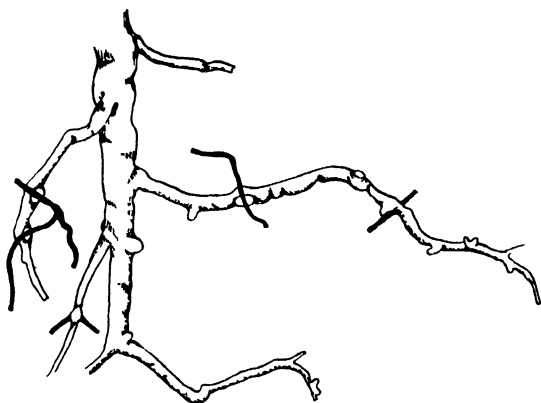

FIG. 32 ROOT OF THE LOUSEWORT (*Pedicularis*), which, like Eyebright or Yellow Rattle, fixes itself by means of suckers upon the roots of its host, and draws nourishment from them Here detached pieces of the root of the host appear black, and are firmly fixed to the thick roots of the parasite. (After Maybrook)

effect of the parasite, so that in meadows, where it often infests clearly marked patches, these are readily recognised by their starved appearance as you approach them, long before the parasite itself can be seen among the herbage. Several other plants of the same alliance, such as Eyebright, Bartsia, Cow-wheat, and Lousewort, share this habit, and all in varying degree deteriorate the crop (Fig. 32). Other allied plants go even a step further : the Broomrape, with its tawny shoot, is a completed root-parasite on clover, and cannot carry on photo-synthesis itself at all (Fig. 33). A

Fig 33 —A Brown Parasite, the Broomrape (*Orobanche minor*), parasitic upon the roots of the white clover (*Trifolium repens*). The parasite is of larger size than its host. (⅓ size, after Strasburger.)

still more destructive parasite of clover-crops is the *Dodder*, for it spreads widely from plant to plant, attacking sharply defined patches in clover-fields, which are then marked by their reddish colour and by the low stature of the starved herbage. It is really a Convolvulus which has improved upon the climbing habit of that plant, so that, instead of merely twining round the supporting plant, it penetrates by its suckers into the tissues and draws its whole nourishment from them (see below p. 269). Over and above these more obvious parasites there is also the whole army of parasitic Fungi, which may weaken in varying degree the plants that the farmer desires to cultivate. But these do not take such a toll from his grass-land as the Rusts and Smuts do from his corn, or the blight from his potatoes.

All the herbage of meadow and pasture, whatever its constitution, is under the sway of the seasons ; and according to these its management by the farmer is determined. The dormancy of winter gives way to the gradually awakening activity of spring, and the tender leaves of grass assume their vivid green. The dairy stock, stall-fed in winter, are turned out into the pastures for daily lengthening periods as the season opens out, and a balance has to be held by the farmer between the activity of growth of the feed on the one hand, and on the other the period of the entry of his cattle on the grass and the number of head per acre. In the south of England early pastures are ready after the end of March, but further north cattle may not be turned out till May. The advance of the season soon makes itself felt in the dairy records, and the climax is usually reached after the summer solstice. As the season advances further the growth diminishes, till in

the autumn the pastures again pass gradually into the dormancy of winter, and the cattle have again to be stall-fed.

The seasonal progress of events is more marked in meadow-land : for there the grasses all grow un-checked to the flowering stage, together with a full development of lateral stolons and their leaves, thus filling up the bottom-grass. The aim of the farmer will be to secure his hay-crop at the moment when the greatest amount of food-material is still widely distributed throughout the leaves, and before it is used up in the full woody development of the haulms, or concentrated in the maturing grains. This is so at or shortly after the summer solstice, which is the time when the grasses are in full flower. But early droughts, late seasons, and particularly the broken weather which so often comes early in July, are apt to delay the timid or the greedy farmer beyond the ideal moment. It is better to cut the hay-crop too early and have it short in quantity, than to cut it too late and find it leached out with rain, or laden with seeds that are shaken out in the handling, or with woody tissues that are difficult of digestion by cattle.

After the hay-crop is taken the growing season is not over; though few grasses flower again, both grass and clover form a rich aftermath, or " fog " as it is called in Yorkshire, a very different thing from *Holcus*, the " Yorkshire fog " so called by those who do not inhabit that county. Sometimes in favourable seasons a second crop of hay may be taken from this aftermath, but that is an exhausting method, and it is usually grazed down by cattle or sheep. Such feed in low-lying grass-land forms a rich foundation for the final fattening of beef for the Christmas markets. At the

same time, when the second crop is thus eaten off upon the land most of its substance remains as a manurial dressing for the following season.

In ancient days, as the winter drew on the stock on the farm was greatly reduced. Superfluous cattle were slaughtered and salted down for food during the winter. It may be going too far to suggest that the exigencies of winter feed for stock thus determined the period of Lenten fasting. But it is undeniable that abstention from meat for a period in the spring would help to eke out the store of the beef-tub at the very time of year when it was likely to be at its lowest. Thus we may see in how high a degree the march of the seasons dictates primarily the practice of present-day farming, and also how in the past it may have had its influence upon the habits of the populace at large.

CHAPTER VIII

WOODLAND

IN the opening pages of *Hereward the Wake* Charles
Kingsley draws what is probably a fair picture of the
eastern counties of England at the time of the Con-
quest. He describes how the low rolling uplands were
clothed in primeval forest, consisting of Oak and Ash,
Beech and Elm, with here and there perhaps a group
of ancient Pines, ragged and decayed, and fast dying
out in England, though lingering still in the forests of
the Scottish Highlands. Between the forests were
open wolds, dotted with sheep and golden gorse, and
rolling plains of rich though rough turf. A large part
of England at the Conquest must have illustrated the
age-long struggle between grass-land and woodland ;
but already the balance was being shaken in favour
of the grass by the self-serving hand of Man. That
balance has tipped heavily since then, and British
woodlands have shrunk to a mere vestige. Even the
native Pine forests of Scotland are often barely trace-
able by a few naturally sown trees, thinly scattered
on hillsides at such spots as Glen Falloch or the Moss
of Rannoch ; but some native Pine-woods still remain,
such as Rothiemurchus Forest in Inverness, and Bal-
lochbuie Forest on the slopes of Lochnagar. From

being a well-wooded land Britain has been cleared
almost completely of her primeval woods, and except
for hedge-row trees and such timber as is raised by
enterprising landowners she has become dependent
upon supplies from abroad.　Much of the forest clear-
ance in our own islands, as well as some of the planting.
has in the past been due to the requirements of
shipbuilding, so necessary to a maritime nation.
Since steel supplanted wood that demand no longer
exists.

Britain is not alone in this destruction of woodland.
The whole world seems to be living a spendthrift life,
consuming ancient timber, and often wasting it by
sheer carelessness—-at a much greater rate than Nature
unaided can possibly replace the loss.　Happily Canada
still holds rich reserves ;　but America, having made
great inroads on her vast woodlands, is already be-
ginning to draw deeply upon the forests of the Pacific
slope.　South Australia is anxious about the shrinkage
of her supplies of Eucalyptus.　Ceylon and the Malay
States, as well as other tropical countries, are rapidly
converting their hill forests into plantations for
Rubber, Cinchona, Coffee, and Tea.　These are mere
examples of the widespread destruction which is fol-
lowing upon the rapid growth of world-population,
and the enormous increase in the use of wood and of
wood-pulp in modern life.

Casting our eyes back upon the wide vista of human
life, the use of timber for fuel, for shelter, and for a
hundred other purposes is almost as conspicuous and
constant as that of grains, leaves, roots, and fruits for
food.　In particular, it is a striking fact that the
migrations, discoveries, and traffic of Man by sea have
till recent times depended upon materials of vegetable

origin, both in the vessels that have carried him to the ends of the earth, and in the means of their propulsion. Yet even these drafts upon the forest, which have penetrated so deeply into the story of Man's life, account for only a part of his exacting inroads upon it.

The climatic facts, however, remain essentially the same as before those inroads became a feature in the countries affected. If this be so, then it should be possible for Man to right the balance, and by protection and cultivation to restore much or all that has been lost. A necessary element is time, for the growth of timber is slow. This means the exercise of foresight and self-denial, without which any scheme of reafforestation is impossible. The Governments of some countries have already taken the necessary steps to meet the growing shortage. This is conspicuously so in France and Germany, where extensive forests are under State control. They are managed on strictly scientific principles, so as to secure a steady and permanent supply of timber. Before the war the royal appanages of Russia included vast forest areas held by the Czars as a regular source of income. Time will show what will be the future fate of those forests. British India has long possessed a highly trained forest service ; Great Britain herself, aroused by the serious warnings of the Great War to a sense of her weakness in woodlands, is at last beginning to take action, though slowly, towards reafforestation under Government subvention and control. The raising of a crop that matures as slowly as timber does, is a matter for public rather than for private enterprise ; while the product itself is of greater importance to the public than to any private producer. The future will probably see all Governments compelled by the impending

world shortage, and by the consequent rise in the
price of wood, to embark upon forestry under State
control. But those Governments that do so the earliest
will fare the best, supposing the conditions to be equal.
This leads to the question, what are the conditions
which would favour the growth of woodlands ?

The climate that encourages woodland in the age-
long struggle with grass-land is that which gives a
warm vegetative season.   In particular a continuously
moist subsoil is important, with damp and calm air
especially in the winter. So long as the subsoil re-
mains moist, the rainfall may be unequally distributed
during the year.   On the other hand, a climate with
a dry winter atmosphere is unfavourable for woodland,
especially if windy, since the roots of trees cannot re-
place from the cold soil the water lost in transpiration
from their exposed shoots. The conditions that favour
grass-land are moderate heat, together with frequent
but light rainfall during the vegetative season, so as
to moisten the surface soil.   Dryness and winds during
the resting season are not harmful to grasses, but
drought during the growing season acts as a serious
check.   It will be clear then that such insular condi-
tions as prevail in Britain would serve for either wood-
land or grass on any average site, so that under the
guiding hand of Man the balance between the ancient
combatants can be varied almost at will.   The con-
clusion which follows from these considerations is
that if Britain wants timber she can grow it again on
such areas as were occupied by her primeval forests.
In the past she has preferred grass, and has carelessly
destroyed her woods ; in the future she will have in
her own interest to rectify the balance. Happily
this need not be largely detrimental to grass-land, as
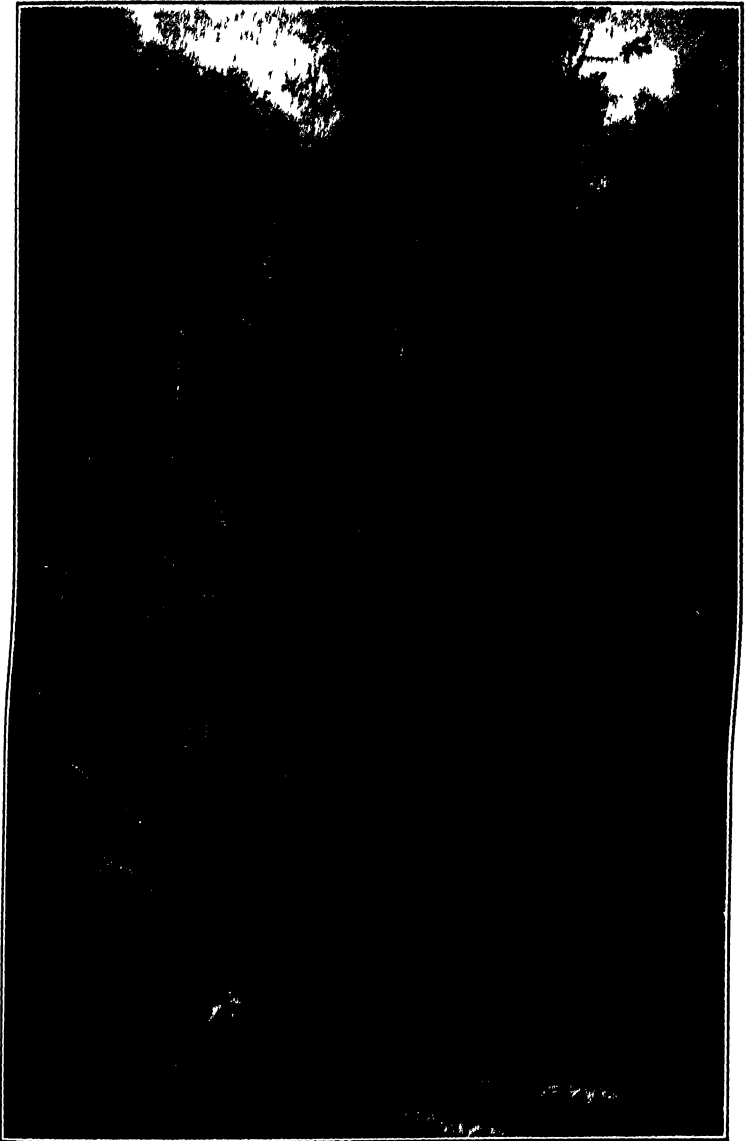
Fig 34 —South-Mexican Rain-Forest, showing the densely crowded vegetation, and in particular climbers (*Araceæ*) fixed to tree-trunks by clasping roots, and with long aerial roots pendent from the vegetation above Higher up are also bushy epiphytes (After a photograph by Dr G Karsten, from Schimper)

there are large areas in the north, not highly culti-
vated for grass, which would nevertheless be suitable
for forest.

When dwellers in highly cultivated countries, with
a temperate climate such as ours, speak of woodlands
they are apt to think of limited areas covered by broad-
leaved trees, and surrounded by arable or grazing
land : or of coniferous woods on highland hillsides,
dark and dense, that are usually fenced, but some-
times shade off imperceptibly into the open moorland.
These are, it is true, the usual alternative types of
what are sometimes called " summer forests " of tem-
perate zones, for they are dominated in their growth
by the succession of the seasons.   We see their activity
arrested every autumn— in the " fall," as it is called
in America since it is then that the broad-leaved
trees shed their leaves and enter upon their winter
rest, while the Pines also lose their activity.   But such
experiences at home give little idea of the forests of
the tropics, and in particular of those hilly areas close
to the equator, where rain falls almost daily, and the
air beneath the high leafy canopy is seldom far below
the point of saturation.   The rank undergrowth drips
with moisture in these " rain-forests " (Fig. 34, p. 87).
Shade-loving herbs and shrubs cover the forest floor.
Climbers, with their head of leaves and flowers far
above, hang their flexile stems or roots like cables from
the trees ;   while perched upon the branches are epi-
phytic flowering plants, ferns, mosses and lichens.
These extend even to the close canopy of branches
above, and there form a topmost stratum of vegeta-
tion, the richness of which can hardly be guessed from
anything visible from below.   This is the natural home
of many Orchids.   The riot and exuberance of the real

rain-forest, the full population, and the competition
for space amongst vegetation, built in flats like any
crowded town, are difficult to realise without actually

FIG 35 THE LEAFLESS STATE OF THE COTTON TREE (*Bombar
malabaricum*) at the dry season in Ceylon Its pendent fruits are
seen (From a photograph after Schimper)

seeing these things for oneself. And yet the colours
are usually sombre as seen from below : greens and
browns prevail, and brighter tints rarely strike the eye
of the traveller. Such growth in the equatorial zone

Photo H. Irving

FIG 36 — WHITE POPLAR (*Populus alba*) SUMMER
From Groom's *Trees and their Life Histories*

FIG 37 — WHITE POPLAR (*Populus alba*)   WINTER
From Groom's *Trees and their Life Histories*.

may be continued without break the year round.
Rain-forests are evergreen, for they enjoy a perpetu-
ally moist summer.

There are, however, regions in the tropics where
seasons are strongly marked, not only by variations of
temperature but by drought. In lands subject to the
monsoons the dry season checks growth. The trees
are in danger of losing more water by evaporation
from their leaves than their roots can supply. Many
of them drop their leaves, and stand stark and bare
in the heat as our own native trees do in the cold of
winter (Fig. 35, p. 89). By so doing they avoid the risk
of drying up, and enter a state of drought-dormancy,
waiting for the breaking of the monsoon. With the
rains activity is again resumed, and a new suit of
leaves is formed. This is the behaviour of many broad-
leaved trees of the tropical dry forest. How then will
it compare with what we see in autumn in our own
woodlands at home ?

The behaviour of trees in our temperate climate is
entirely different as to the conditions, however similar
it may seem to be in external appearance. Nothing
except a sudden fall of snow alters the whole face of a
well-wooded British countryside so much as the fall of
the leaves in autumn (Figs. 36, 37). But the event has
become so familiar by annual repetition, and it is so far
softened by the absence of suddenness in the change
that it appears to us less notable than it really is.
Excepting some few evergreens, our native trees and
shrubs alter their whole aspect in the course of a few
days, and the change is heralded by the familiar tints
of autumn. The few native woody plants that retain
their leaves through the winter provide by ancient
custom the Christmas decorations —Holly, Ivy, Scots

Pine, Yew, Mistletoe, and locally the Juniper. No
one can help remarking how stiff and leathery, or even
spinous, are the leaves of all these native evergreens,
as are also those of introduced trees and shrubs that
withstand our northern winter—for instance, various
Conifers, the Turkey Oak, Cherry-Laurel, Laurustinus,
and the Rhododendrons. It will appear presently
that there is more than mere
coincidence in this.

The physiological change of
woodlands in autumn is not less
striking than the scenic, for by
the simple device of leaf-fall
trees reduce their exposed sur-
faces. The proportion of surface
to bulk in any ordinary leaf is
great, and in summer the number
of the leaves borne by a twig
may be great also. Comparing
the total of such exposed surfaces
with that of the naked twig as
it enters its winter rest, the
difference will appear in its true
proportions. The exposed sur-
face in winter is a very small
fraction of that in the summer

FIG 38.—WINTER-BUD
THE BEECH (*Fagus sylvat*
covered with protective scales
(*kns*), and showing the small
proportion of exposed surface
in the defoliated state. Natural
size. (After Strasburger.)

state (Fig. 38). A further examination of the twig
itself shows not only its compact cylindrical form, but
also how perfect is its surface-protection. An out-
side skin of impervious cork gives it the usual brown
tint. Even the lenticels, or secondary breathing
pores, are often closed in winter, while each bud is
covered by efficient scale armour. Defence is written
large over the whole of the dormant leafless tree ; in

particular the risk of evaporation from the surface is
reduced to a minimum. But why should there be
any risk, it will be asked ? The winter rainfall is
ample, the soil is wet, and the roots are all there,
buried in the moist soil. Yes, but the soil is cold and
the roots are dependent upon temperature for their
power of absorption. This may be seen by chilling a
flower-pot with ice, when the plant within will wither.
Such would also be the winter condition of a leafy tree
with its roots chilled in the cold winter soil. It is this
which makes the autumnal leaf-fall intelligible, also
the leathery foliage of such evergreens as keep
their leaves. For such leaves are specially able to
control the loss from surface evaporation, hence the
plants which bear them are able to survive even though
their roots are checked in their absorptive activity.

In many primitive plants and in most herbs the
leaves simply rot away in the autumn, leaving decay-
ing stumps. But when broad-leaved trees shed their
leaves it is by a cut as neatly carried out by Nature as
an operation by the most practised hand of the surgeon.
If you examine the half-moon shaped scar left on a twig
of the horse-chestnut when a leaf falls away, you will
see a neatly healed surface marked by five or seven spots
arranged in a curve (Fig. 19, p. 40). These show where
the vascular conducting strands ran out from the stem
into the leaf-stalk. Their vessels and sieve-tubes will
all need to be ligatured as much as the arteries and
veins in an amputation, and a minute examination of
the scar shows that they are all tightly closed. Before
a leaf is actually shed a corky band is formed trans-
versely across the leaf-base (Fig. 39). Meanwhile the
cells just outside this become rounded so that their
attachment is weakened. This is the abciss-layer along

which the rupture comes. A touch of early morning frost will often hasten the fall even in still air; or the leverage caused by a breeze will break the weakened attachment. But when the leaf falls the surface of the scar is already sheathed with impervious cork, while the lateral pressure of the cells on the vessels and sieve-tubes has closed them just as a rubber tube may be closed by a clip. The scar is thus secure against loss from within, as well as from the intrusion of germs of disease from without. That this is of no small moment to the tree as a whole is obvious when we remember that each falling leaf involves a wound. On the other hand, the leaf that is cast off is a thing no longer of value to the plant, for all the food-stuffs have been passed back into the twig for storage, to be used up in forming

FIG. 39 —VERTICAL SECTION THROUGH THE BASE OF A PETIOLE (*pet*) of a Horse Chestnut at its junction with the axis, showing the abciss-layer (*ab*) with cork beneath it (*ck*). *l* a lenticel. When the leaf falls the scar is protected, and the axillary bud (*ax. b*) is left attached.

leaves or flowers in the spring. The cells are all empty except for water, tannin, and other effete matter. The falling leaf has served its end; it is now a mere framework of cell-walls.

So far only broad-leaved trees have been considered: but as we travel northwards in Britain a change is apparent from deciduous to evergreen woods. The question arises how the Conifers that form them will

fare under those seasonal changes to which leaf-fall
has been ascribed. The *Pinacea* which form the
extensive forests of the north temperate zone are
socially growing trees, often forming pure tracts to
the exclusion of other trees. In Northern Britain the
natural woods, now almost obliterated, consisted
chiefly of Scots Pine, but modern planting of this and
other species accounts for nearly all the coniferous
woods we see. The structure of their stiff, needle-like
leaves keeps a check on transpiration ; and in winter
this is specially important for Scots Pine, Silver Fir,
and Spruce, which are evergreens, for it protects them
as efficiently as the leaf-fall of the broad-leaved trees
from the risk of being parched in winter. On the
other hand, the Larch, so widely used in planting
though not a native, is deciduous, and its leaves re-
semble more nearly in structure those of the summer
foliage of broad-leaved trees. Thus the leafage of
Conifers will support the conclusion already drawn
from broad-leaved trees, that restriction of evaporation
in winter is essential for the existence of woodland
wherever the seasons are strongly marked.

Woody plants, whether deciduous or evergreen,
when living where seasons are sharply defined, enter
perforce a period of winter rest. Their general phy-
siology is checked, and the fact is registered more or
less clearly in the structure of their trunks, limbs, and
twigs. As the new suit of leaves expands in spring,
new spring wood of open texture is formed outside the
old to meet the insistent demand for water supply.
But as the summer advances the wood formed later
is harder and denser, giving added strength rather
than increased power of conduction to the stem. A
sharp external limit marks the end of the season's

activity , and so each year stamps its record in its
annual ring of wood, disclosing not only the age of the
tree, but also giving some evidence of each season's
success by the width of its particular ring (Figs. 40,
41). The rings are, however, merely physiological
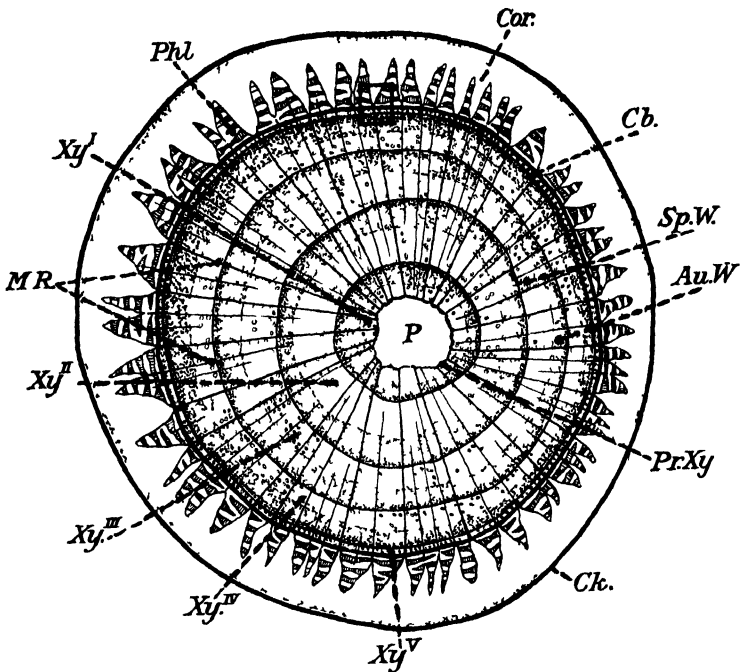
FIG. 40. TRANSVERSE SECTION OF STEM OF LIME cut in the
spring of its fifth year. *P* pith. *Xy¹* to *Xy⁵* wood of the first to
the fifth seasons. *MR* medullary ray. *Sp.W* spring wood.
Au.W autumn wood. *Phl* phloem or bast. *Cb* cambium.
Cor cortex. *Ck* cork. (12) Four annual rings are com-
pletely formed each with an inner zone of spring wood and an outer
zone of autumn wood the wood of the fifth ring is just beginning to
appear *Xy⁵*

records; they are not inherent features of the organism,
as may be seen from the fact that rings are indis-
tinguishable in many tropical trunks, while an inter-
seasonal check caused by drought, or by caterpillars
devouring the first suit of leaves, may result in a
second suit of leaves being formed, with a doubling

of the ring, one narrower ring corresponding to each
of the interrupted periods of activity.

Returning finally to the competition between grass-
land and woodland, with special reference to their
balance under the seasonal conditions of our British
climate, we may inquire how the competitors them-
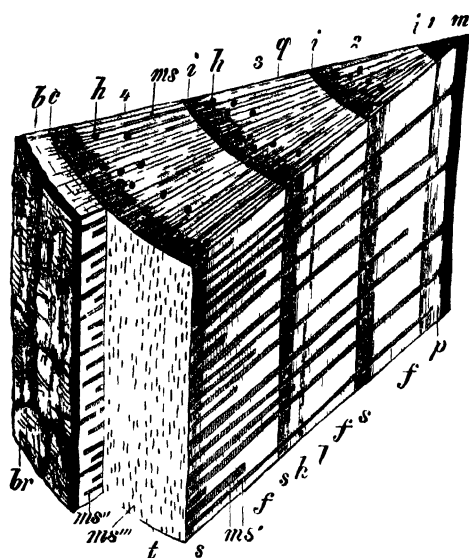
FIG. 41.—WEDGE CUT RADIALLY OUT OF A FOUR YEAR OLD STEM
OF PINE IN WINTER. The structure is in general plan the same as
in broad-leaved trees. *q* transverse surface. *t* radial surface.
t tangential surface. *f* spring wood. *s* autumn wood. *m* pith.
p first formed wood. *h h* resin passages. 1 2 3 4 successive
annual rings. *ms* medullary ray in transverse view. *ms ms* in
radial view. *ms* in tangential view. *c* cambium. *b* bast.
br bark. (× 6.) (After Strasburger.)

selves differ. The differences are in stature and in
habit. Trees grow tall and root deep ; they expose
a large surface to air and light, and risk much in the
drying winds of winter, a risk that is suitably met by
the autumnal leaf-fall that so greatly reduces their
exposed surfaces. But they have access to compara-
tively deep levels of the soil, where the water supply
is relatively constant. Grasses are low of growth and

shallow in their rooting. By their habit as herbs they are less exposed than higher growths, and their herbage withers in autumn, while snow will often protect what remains above ground against the extreme rigour of winter. Their shallow rooting makes them dependent upon intermittent showers that wet the surface, rather than upon the deeper reservoirs of the soil. Either of these types of vegetation will succeed in our insular climate, with its absence of extreme conditions. It is where the seasonal changes are more stringent, as in northern and continental lands, that the struggle between them becomes intense. Any slight change in the balance of conditions may then favour the survival of the one or of the other, and decide whether a district shall be characterised by forest, or by prairie and steppe.

CHAPTER IX

MOOR AND MOUNTAIN

THESE very words suggest holidays and sport : space, freedom, and life under natural conditions. Large areas in Britain, of little use for intensive cultivation, remain untilled, and not far removed from their primitive state. They often appear as moorland. Free from timber excepting in protected gills or hollows, or sparsely dotted with isolated trees or low scrub, a stunted vegetation covers these wind-swept and often upland tracts, offering little or no obstacle to the sportsman or the tourist. On wet ground in cooler climates there may be below the mantle of living plants a profuse formation of Peat, the accumulation of the remains of plants now dead. But in warmer climates and on drier soil, owing to a quick decomposition of organic substance, large growths of Peat are less common, and a sandy or rocky floor is soon reached. It is the Peat that gives a special character to these open spaces, rounding the contours of the rocky skeleton below with a mantle of variable thickness. Its presence is the leading feature of what we call Moor.

The word " moor " is often used in a generally descriptive rather than in a scientific sense, and it has been

applied to areas that differ widely from one another
in level and in soil, as well as in the vegetation that
covers the surface. Thus we may speak of grass-moor,
where the covering is chiefly of grasses or sedges,
browsed by sheep ; or of heather-moor where the
Heath family is prevalent. The soil may be alkaline,
as it is in the low-lying black soil, with high mineral
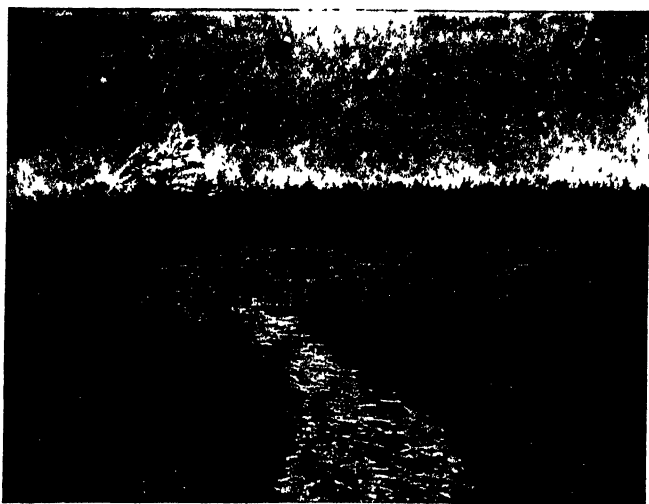
FIG 42 — A SCENE AT CROCKHAM COMMON, KENT, showing sub-
spontaneous Pine-wood, with Heath-association, occupying the open
space, consisting of Heather, Heath, and Bracken The subsoil is
the Hythe beds of lower greensand (After Tansley)

content, in the Fens of Lincolnshire and Cambridge ;
or it may be acid, as it is in the purer peat of the up-
land heather-moors of the north. Again, many low-
land areas are covered with but a thin layer of Peat
overlying a sandy sub-soil, and these support chiefly
Heaths and Bracken. Such lands are a widespread
feature of the low-lying areas of East Anglia, and are
common in the neighbourhood of Camberley and
Aldershot (Fig. 42). But the most characteristic
moors, in the ordinary acceptance of the word, are

those uplands where the Peat is deep and acid : it
bears certain distinctive plants, and in particular the
Heather, upon which grouse feed.   The use of the word
" moor " conveys to the ordinary man the ideas of an
upland surface, mainly covered with Heather, and with
underlying Peat, as it is found on the hills and lower
slopes of mountains in the north (Fig. 43).
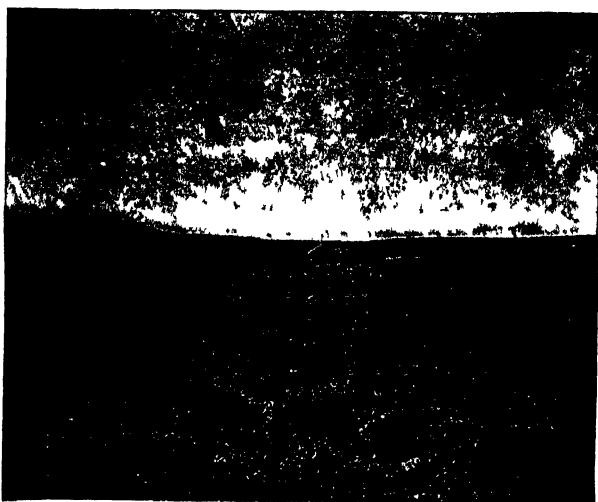
FIG. 43.   HEATHER MOOR IN THE PENNINES (August)   (After
Tansley from a photograph by W. B. Crump.)

The chief factor in the formation of Peat is the Bog-
Moss (*Sphagnum*) (Fig. 44).   Few plants influence a
larger surface on the globe than Bog-Mosses.   This
results from certain structural features which they
possess.   If we walk over a moor where Sphagnum is
plentiful our feet are soon wet, even on a dry day.
As the foot sinks into a soft cushion of Bog-Moss the
water oozes out as from a crushed sponge.   If you
take a handful of the bright green moss and squeeze
it firmly, water is wrung out, while the moss itself
changes to an opaque buff colour.   The power it

possesses of holding water is due partly to the way in
which the numerous leafy branches of each stem cling
closely round it (Fig. 47, *A*) ; but chiefly to the fact
that its thin leaves consist of cells of two sorts ; nar-
rower cells with living green contents that form a sort
of vital framework.   Its meshes· are filled by cells
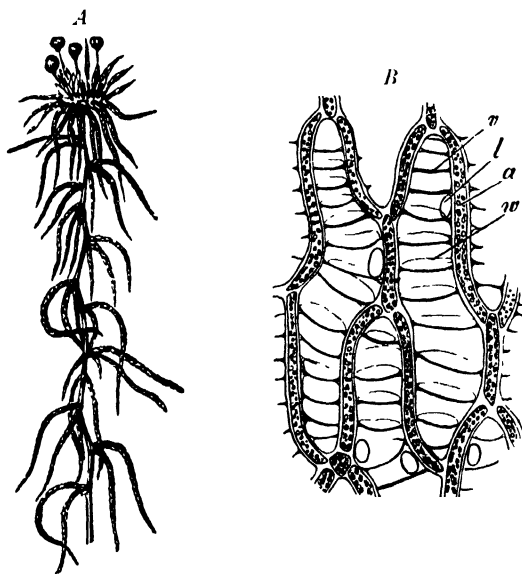
FIG. 44   *A*   a single plant of *Sphagnum fimbriatum*, bearing
apsules above   Below are the thin leafy branches, which often
row closely oppressed to the main stem   *B*   a few cells of the leaf
f *S cymbifolium* highly magnified.   *a* the living green cells ;
· the dead water-containing cells, with their thickening bands (*w*),
nd pores (*l*)   (After Schimper.)

without contents ;   their hollow cavities hold water
which can pass in or out through large circular pores in
the walls (Fig. 47, *B*).   It is the squeezing of this water
out, and the substitution of air for it that causes the
change of colour above noted.   Thus the texture of
the plant in mass is doubly spongy : there is a coarser
texture of closely coherent branches, and a finer
microscopic sponge due to the cellular construction.

It is this singular constitution, combined with the free-
dom from germs, that gave the hill-Sphagnum its place
as material for surgical dressings during the Great War.
The purity of the hills, thus brought to Man in his
extremity, was a special instance of the health-giving
qualities of the moor.

Glacial Succession	Spey Findhorn watershed 1800-2100 ft	Corrie Bog Easter Ross 1400 ft	Findhorn Cairn watershed 1900 ft
	Recent peat chiefly Scirpus & Sphagnum	Recent peat chiefly Scirpus & Sphagnum	Recent peat chiefly of Scirpus & Sphagnum
	Pinus sylvestris	Pinus sylvestris	Pinus sylvestris
	Sphagnum	Sphagnum	Sphagnum
Upper Forestian or 5ᵃ Interglacial Stage	Pinus sylvestris	Pinus sylvestris	Pinus sylvestris
	Sphagnum & Eriophorum	Sphagnum & Eriophorum	Sphagnum & Eriophorum
	Betula alba	Betula alba	Betula alba
	Empetrum	Empetrum	
	Salix Arbuscula Arctostaphylos alpina Salix reticulata & herbacea	Salix Arbuscula Betula nana Dryas octopetala Salix reticulata	Salix Arbuscula
Lower Turbarian or 5ᵇ Glacial Stage			

FIG. 45.—(After Lewis.) The succession of Peat strata in the
north-east Highlands is shown, and it will be seen how successive
growths of woody plants with their roots and stems in their natural
position have been embedded by the upward growth of the Peat.

If any plant of Bog-Moss be followed from its active
apical bud downwards, a point will be reached where
the tissues are no longer alive. The dead base is pro-
spective Peat. The Bog-Moss is ever growing upwards,
with death following behind ; this is the way that
high moor is formed ; the Moss, and below it the Peat,
continuously growing upwards. It envelops rocks
and tree stumps, forming gradually a mass of brown
humus that is compacted by pressure from above

(Fig. 45). The Peat thus produced is a poor soil for other plants, and this has the effect of restricting the moor-flora. In the first place, the acidity of the soil-water checks the absorptive power of roots; consequently the vegetation that accepts a peaty situation will absorb little by its roots, and must accordingly be so developed as to economise the loss of water by evaporation from its leaves. The effect of this appears in the minute, curled-up leaves of Heather and
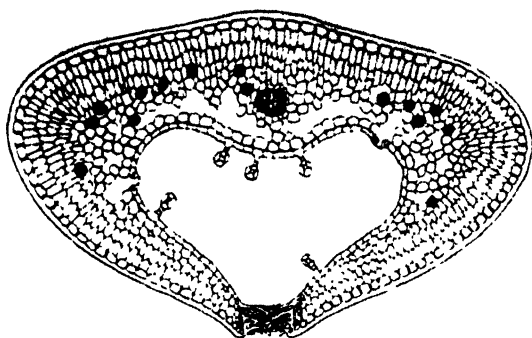
FIG. 46. TRANSVERSE SECTION THROUGH A LEAF OF THE CROW-BERRY (*Empetrum nigrum*), showing how it is curved backwards, so that the two margins close together, thus almost enclosing a hollow space; this i lined by the lower epidermi bearing stomata, which thus op a into an almost saturated cavit loss of water vapour them is thus checked (0.) This method of restricting t nspiration is common in moorla (After Schroeter.)

of the Crowberry; their evaporating surface is thus greatly reduced and protected (Fig. 46). Further, the soil is poor in minerals, a natural consequence of the remoteness of the surface from the mineral substratum. But the greatest obstacle is the poverty in available nitrogen. Nitrogen is actually present in quantity, but not in an available form. Moreover, nitrifying bacteria, that convert ammonia salts into nitrates, are deficient, while the bacillus that co-operates so effectively, as we have seen in Chapter VII, with the

Clovers and Vetches in the well-being of grass-land,
does not prosper in peat-water.   On the other hand,
the moorland flora often enlists, as a set-off to such
difficulties, the co-operation of Fungi, as in the Heaths
and Orchids.   This will be explained in Chapter XXIV
on *Mycorhiza*.   Thus they are enabled to succeed on
this unpromising soil.   Further, some of the plants
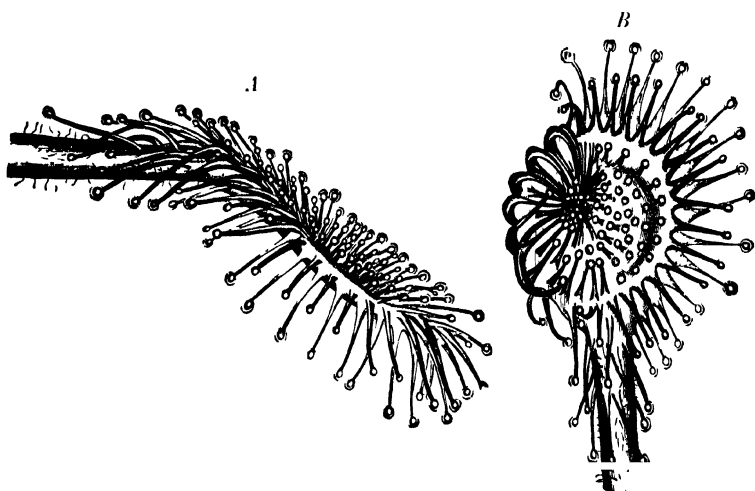
FIG 47   LEAVES OF THE SUNDEW ENLARGED, showing the con
struction of the fly traps   A is in the receptive state with the
tentacles each bearing a glistening viscid drop of secretion extended
B is the state after stimulation seen from above with the tentacle
incurved so as to surround the stimulating body, for instance a
insect attracted by the glistening drops, and then held by their vis
cidity   (After Darwin)

of the moor show a still more sensational feature,
which conduces to successful nutrition.   They resort
to the carnivorous habit, which makes up for the de-
ficiency of available nitrogen in the soil by capturing
and digesting the bodies of small animals.   This is
seen at home in the Butterwort and the Sundew, both
common moorland plants (Fig. 47).   A similar habit
appears in *Sarracenia* and the Venus' Fly Trap, in like
situations in America.   Thus the biology of the Peat-
moor is the record of a physiological struggle against

adverse circumstances for other plants than the Sphagnum itself.

Passing upwards through the moorlands to the higher mountain levels, we reach the region of an Alpine, or better of an Arctic flora. This is the summer resort of the red deer. Much of the land designated deer-forest actually lies above the limit of growth of trees, a *lucus a non lucendo* not readily grasped by the Southron. Everyone knows that as we climb upwards the character of the vegetation changes ; but it is not possible to assign any strict limit between the temperate zones below and an Arctic zone above, since the species overlap. It often happens that when the seeds of the Arctic plants are washed down from their higher stations by streams, the seedlings flourish quite well at points below their usual level. It is in the geographical spread of the species that their Arctic character becomes most apparent. It may truly be said that the mountain tops of Britain, and especially of Scotland, carry an Arctic flora, for many of the same species as are found there spread northwards, and are actually at home within the Arctic Circle. The flora of the higher Scottish hills is very similar to that of Scandinavia, and many of the same species appear as we ascend the White Mountains of New Hampshire. A further and a very cogent example is seen on the Tunnel Mountain, near Banff, in the Rocky Mountains. There at the higher levels a large proportion of the plants belong either to species actually living in Scotland, or are very nearly allied to them. They also are Arctic. There is in fact a close affinity of the mountain flora of North America with that of Scandinavia and of the Scottish hills, and ultimately with that of all Arctic lands.

The meaning of these striking facts probably is that these isolated areas constitute what is left of an Arctic flora which was, as it still is, circumpolar ; but it extended long ago over much larger and more coherent areas than its present species hold.   It was characteristic of the last Glacial Period, when Arctic conditions obtained over a great part of the northern
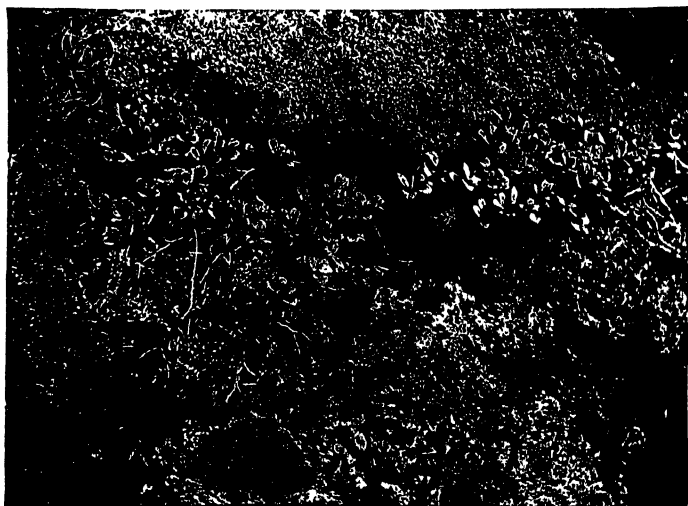
FIG. 48.—ARCTIC VEGETATION AS SEEN ON DRY MOUNTAIN LEDGES. The moss is *Rhacomitium lanuginosum*, and below it is seen *Salix reticulata*, one of the Arctic willows.   (After Tansley, from a photograph by F. F. Laidlaw.)

hemisphere.   By their hardy constitution and various points of specialisation, the constituent species were able to maintain a bare existence under most inhospitable conditions, and formed the flora that snatched the short summers that intervened between the long frozen winters of glacial times.   As those conditions softened off to our present climate, the Arctic species were crowded out by stronger-growing species that intruded from the southern temperate lands, while the former retired before them to those mountain

fastnesses where they still survive.   It is chiefly where
precipitous hill-sides face the north-east, and the
exposed rock is carved into irregular ledges that
hold the soil, while water trickles slowly down, that
these relics of a vegetation
once more widely spread may
still be found on the Scottish
hills (Fig. 48).

Space does not allow of
entering here into the details
of adaptation which have
enabled these Arctic plants
to maintain life in their in-
hospitable surroundings.   We
may note that they are per-
ennials, of low stature, with
abnormally large roots, and
relatively small, often rosette-
like shoots, and that many of
them propagate by bulbils
rather than by seeds.   Their
general features are in fact
such as will enable them to
make the best of a short
season, rooted in soil of low
temperature.   Often   their
flowers   are   of   a   singular
beauty, though they are not

FIG. 49.—*Primula minima*, an
example of a dwarfed Alpine species,
with extensive roots (broken off
short), perennial stock, small rosette-
like leaves, and a single relatively
large flower.   Natural size   (After
Schimper.)

borne in such profusion in Scotland as they are on
the Swiss Alps (Fig. 49).

Many years ago Sir Joseph Hooker, writing upon
the Arctic flora as a whole, drew up two lists.   The
first included 61 species, that were held to be " the
most Arctic plants of general distribution that are

found far north in all the Arctic areas." The second
list of 23 species included those which, "though Arctic,
do not attain such high latitudes as those of the first
list." Of the 84 species which thus constitute the
Arctic flora of flowering plants, no less than 53 are in-
cluded in the British flora, and the very large majority
of these are well-known dwellers on the higher levels
in the Highlands. They constitute in fact the bulk
of what we know as the Scottish Alpine Flora.

We may imagine a gigantic hand with the North
Pole at the centre of its palm, and the fingers spread-
ing southwards over the surface of the globe, thus
corresponding to the main mountain ranges that
radiate from the north. Such a hand might represent
to us the distribution of the Arctic flora as it is to-day.
In glacial times that hand would have been webbed
between the fingers, for the Arctic species would have
filled the valleys and lower ground between the moun-
tain ranges. But as the climate ameliorated and the
ice-cap withdrew, leaving behind such clear evidence
of its existence as the *roches moutonnées*, glacial
scratches, and erratic blocks, the Arctic species will
have followed the retreating margin of the ice, holding
on tenaciously to those very spots where they may
now be gathered in full flower in July. This is the
botanical romance of our northern hills. As we as-
cend to the stations where these relics of the past still
retain a precarious footing, it is impossible to avoid
the romantic glamour which they give to the moun-
tains. Their economic importance is negligible. Like
so many of the survivals of a bygone age, their value
seems to lie only in sentiment or in history. But for
the climber who knows them, they add a peculiar and
imaginative charm to his days upon the hill.

CHAPTER X

THE SEASHORE

FARMLAND and woodland occupy a large part of the
surface of any fully settled country. The woods and
fields of Britain, as we now see them after long culti-
vation and extensive artificial planting, are for the
most part what Man has made them ; in fact, they
are very different from the primitive wild. Moors and
mountains, on the other hand, still keep much of their
natural character. But the part of any country of old
cultivation that retains most fully the original state
of the plants that it bears is the seashore, together
with the submerged rocks far out below the level of
low water. The coast-line is surrounded by a zone
of vegetation that stands now as we may believe it
to have been before the era of cultivation opened. It
forms a belt continuous round the coast, excepting
only where there is shifting sandy beach or mud ;
these areas are deserted, because on such uncertain
ground the marine plants can gain no permanent foot-
hold.

The difference between the flora of the coast-line
and that of the land is very striking. The high-tide
mark is itself a sharp limit separating the firm, more
or less upright land-plants from that limp vegetation

of the shore, which depends for its existence on sea-water. Such dependence may be either permanent or temporary : for some of the plants appear to be content with a short immersion at each flood-tide, and grow near to the high-tide mark ; but others demand longer periods of flooding, while others again require to be constantly submerged, growing only below low-tide mark. Passing through this roughly graded inter-tidal zone, downwards to the low-tide mark and beyond it, we shall naturally ask how far this flora may extend into the depths of the sea. At about 150 feet below the sea-level as a rule all plant-growth ceases, though in some very transparent waters the limit may be deeper still. In point of fact, it is the fading out of the light necessary for the self-nutrition of these plants, by the absorption of its rays in their passage through the increasing depth of water, that imposes a limit on their extension to deeper levels. And so we may understand that this characteristic flora of the coast is limited to a comparatively narrow belt lying between high-tide mark and some 150 feet below low-water. The plants are often crowded together wherever there is a solid substratum upon which to fix themselves ; they form a very dense fringe round the coast-line—but still only a relatively narrow fringe.

This peculiar flora, so restricted in its spread when compared with the great expanse of ocean, is almost wholly made up of Algae –that is, of plants usually called Sea-Weeds. It is true that a few flowering plants allied to the common pond-weeds do penetrate the inter-tidal zone, the most familiar of these being the native Sea-Grass (*Zostera*), common on mud-flats. But with such exceptions it is a sea-weed flora,

composed of many types diverse in size and in affinity.
The beauty of outline, of colour, and of delicate
texture of many of them attracts general attention,
and has made their collection one of the rational
amusements of a seaside holiday. Each plant is fixed
by a holdfast, usually shaped like a disc, upon some

FIG. 50 A photograph of Sea-Weeds taken under water, showing
them in their natural attitudes. They include *Ascophyllum nodosum*
Halidrys siliquosa, and *Fucus serratus*, etc. (Reproduced by permission
from Schensky's *Pflanzenleben der Nordsee*.)

such solid substratum as a rock, a wooden pile, a
ship's bottom ; or it may often be that the smaller are
perched upon some larger sea-weed. A firm anchorage
appears to be essential for healthy growth; and clearly,
since the waves and tidal streams are constantly mov-
ing, this has the effect of exposing the anchored plant
to successively fresh surfaces of sea-water, from which
it draws its nourishment. The holdfast is not an

P,P,M. H

absorptive organ like a root, but it serves merely the
mechanical purpose of fixation ; all absorption of food
is through the surface of the tissues exposed to the
sea-water, or at low tide to the air.
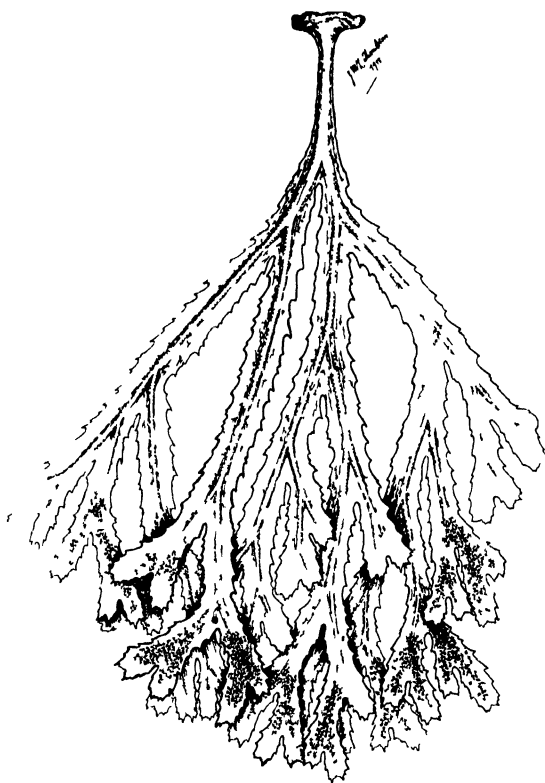
FIG. 51   A DRAWING OF AN ACTUAL PLANT OF *Fucus serratus*
showing the basal disc of attachment, the regular forking of the
flattened frond, and the fertile ends of the longer branches   (½
natural size)

The feature that is most prominent in the larger
sea-weeds is that they may have a flattened, often fan-
like, form.   Botanists say that they show bilateral
symmetry.   But it is not like that of an ordinary leaf,
which has a marked difference between the lower and
upper surfaces ;   here both sides are alike.   A glance

at rocks covered by Brown Tangles exposed about mid-tide level shows the convenience of this, where the limp plants, left in no regular position by the falling tide, overlie and protect one another from the drying sun. On the other hand, a view downwards into deep water, from rocks fringed with Tangles will show how in their native element the flattened form yields to every movement of the waves in a way that a radial construction would not readily allow. This and the leathery consistency of their pliant fronds fits them peculiarly for life exposed to the swirl of the waves. Few large sea-weeds have an undivided frond; usually it is either branched, often by repeated forkings, as in Bladder Wrack ; or it may be torn into ribbons, as in the large Tangles. Clearly sub-division in some form or another is an advantage wherever a large frond is exposed to the risk of damage from the rough action of the waves. The strain may be slight, or even absent in calm weather. Most visitors to the coast do not see, and, not seeing, find it hard to realise, how very exacting the strain may be in the heavy storms of winter.

The plants which constitute this Algal flora fall into three large groups, which are roughly characterised by their colour as Green, Brown, and Red Seaweeds ; not that the mere tint is constant or distinctive, but it happens that the colours mentioned run roughly parallel with those characteristics of structure and propagative method by which the three groups are more strictly defined. The colouring has a physiological meaning in relation to light. Ordinary green plants capture and make special use of the rays near the red end of the spectrum in their nutrition. But the Brown and Red Seaweeds capture rays further

along the spectrum, and it is such rays, in the direc-
tion of the blue end, which penetrate farthest into the
depths of sea-water. It might then be anticipated
that there would be a strict zonation of the shore
according to level : the green forming the highest
band, the brown taking a middle place, and the red
penetrating the deepest. But it is not so. There is
no exact scale of colour-zonation according to level.
Representatives of all may even be found near to the
high-tide mark. But, speaking generally, the red are
certainly more prevalent at the lower levels where the
green are almost absent, and the brown concentrate
about the middle levels. There is, however, more
definite zonation in genera and species. Thus among
the brown Algae the tawny yellow *Pelvetia* almost
takes possession of the highest levels. Various species
of *Fucus* are concentrated at middle levels, while the
strange-looking Sea-Thong, *Himanthalia*, is only met
with below half-tide level. Lastly, the big Tangles
are not really at home above the level of low neap
tides, and are only partially exposed to the air at
low water of spring tides.

No one of these three classes of Algae can properly
be held as the parent of the others. Probably they
constitute three separate but parallel lines of evolu-
tion ; and comparison, whether by structure or by
propagative method, between the representatives of
each confirms this view. The simplest examples con-
sist as a rule of a single cell, or a cell-filament. It
may be seen in each of the classes how by massing of
such filaments together, by developing a cortex round
the single filament, or by webbing the filaments to-
gether like the digits of a duck's foot, a comparatively
large plant-body may have been produced from very

simple beginnings. Lastly, in some of them an ex-
ternal deposit of lime cements the whole together into
a chalky mass, as is seen in the common *Corallina*.
Comparison of the simpler examples of each class
points more or less clearly towards the single cell, such
as is seen to constitute the whole individual of the
primitive Flagellatae, as the prime source from which
they all sprang. Such a cell may be sometimes motile,
but under certain conditions it becomes encysted, and
non-motile, as in the common *Euglena*. On the basis
of such considerations as these the view is very widely
held that the Algae have all been descended from
simple organisms such as the Flagellates, and that
their bodies, however complex, are really aggregates
of such cells in the encysted state. But it is probable
that the three classes advanced independently each
from its own simple beginning, in fact that such simi-
larities as they show are results of homoplasy, or
parallel development.

While a comparative study of various Algae may
thus provide some ideas, however uncertain, as to the
origin of a large plant-body from a simple filamentous
or even unicellular source, a similar study of their
propagative methods has been found to give clues to
the origin of sex. In the simplest Flagellates there
is no sex, and multiplication is only by fission, as in
Euglena. But in other Flagellates a fusion of two
motile cells (gametes) of equal size may occur, giving
rise to a new individual as a result of their common
parentage. This state of equal cell-fusion appears also
in the simplest of the Green and Brown Algae, and it
will be noted that the cells which fuse (gametes) are
motile in water, thus corresponding to the active state
of the Flagellates. As the gametes are alike, there is

here no distinction of sex. But in the Brown Algae
successive steps of difference may be found in types
successively more advanced also in vegetative struc-
ture. These lead to the state where there is a marked
difference in size as well as in motility of the gametes.
The smaller and more numerous male gametes retain
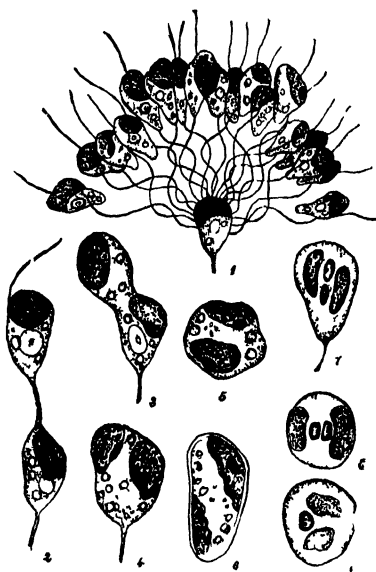
FIG 52 ILLUSTRATIONS OF THE GAMETES (SEXUAL CELLS) OF A
SMALL BROWN ALGA *Ectocarpus siliculosus* 1 female gamete sur
rounded by a number of male gametes 2 5 stages in the fusion of
two gametes 6 zygote 24 hours after fusion 7 9 fusion of the
two nuclei as seen in fixed and stained material (1 5 after Berthold
6 9 after Oltmanns) (From Strasburger)

their motility, but the female gametes, or eggs, are
enlarged so as to carry a store of food material; they
are fewer in consequence, and are non-motile. Ferti-
lisation, that is the fusion of the male gamete with the
female egg, will therefore depend upon the motility
of the former, and the power of attraction exercised
by the latter; while the germ fertilised by the fusion
starts its new life with a store of food already present

in the egg. Thus the provision for the nourishment
of the new germ is the biological foundation for
the distinction of sex. The steps leading to this
distinction are indicated with great clearness by
comparison of various Brown Algae, and they are
equally clear in the Green. There is, in fact, reason
to believe that the distinction between the sexes
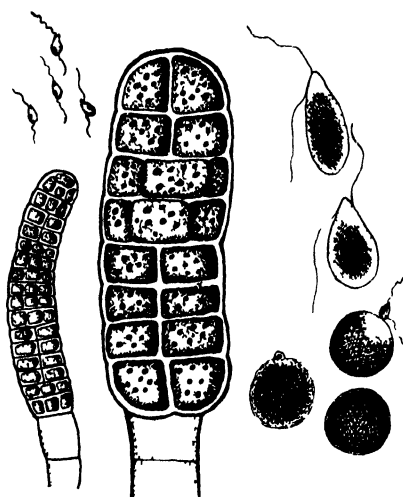
FIG 53 — TWO FERTILE BRANCHES OF *Cutleria multifida*   male
to the left with smaller cells female to the right with larger cells
Top left are the small motile spermatozoids top right are the larger
motile ova   These lose their motility later and become spherical
is seen below where three stages of fertilisation by the small sperma
tozoid are seen   (After Reinke) (500)

has, like the progression in the structure of these
plants, been achieved along a plurality of evolutionary
lines.

It thus becomes obvious how wide and general an
interest the study of the plants of the seashore may
arouse. By comparison of related seaweeds we gain
light upon the evolution of the complex form and
structure which the larger of them show, and we are
able to trace that structure back, in most cases, if not
indeed in all, to that filamentous state seen in the

simplest of them. Similarly, we learn from them how
the steps may have been gradually taken which led
from plants where the gametes were all alike to the
full distinction of sex. That distinction is already
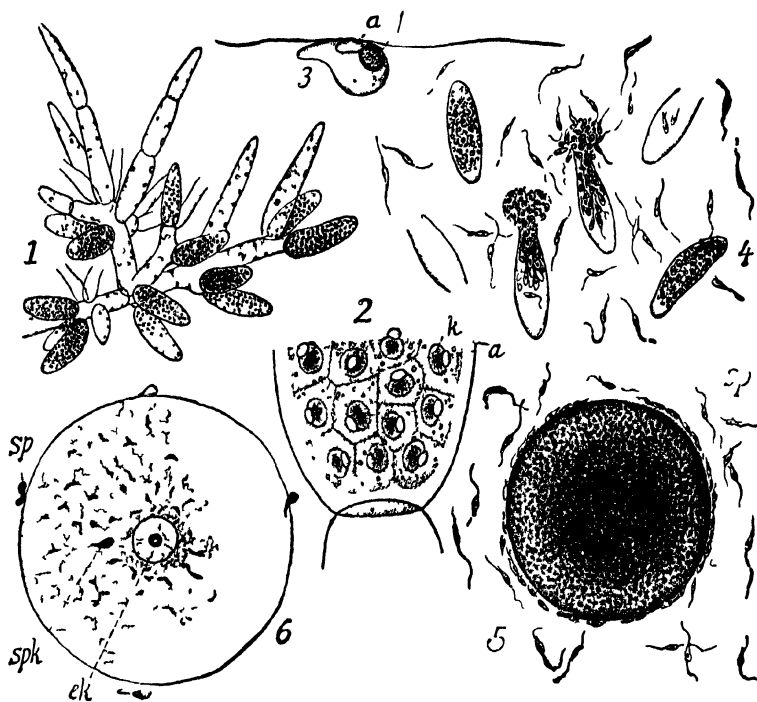
FIG. 54 — PROPAGATIVE ORGANS OF *Fucus* shown under different
scales of magnification 1 a branching hair bearing antheridia
2 part of a mature antheridium showing the developed sperma-
tozoids 3 a single spermatozoid—*a* eye spot *l* nucleus
4 isolated antheridia liberating the spermatozoids 5 non motile
ovum surrounded by spermatozoids 6 section through a fertilised
egg—*ek* nucleus of egg, *spl* nucleus of sperm *sp* spermato-
zoids (1 4 5 after Thuret 2 3 after Guignard highly magnified
6 after Farmer) (From Strasburger)

clearly defined in the common Bladder-Wrack. Various
accessory details may, it is true, be elaborated in
carrying out sexual propagation in land-living plants,
culminating in the extraordinary devices seen in the
flower. But still these are only accessories. The
fundamental fact of sexuality is established as securely

in the Bladder-Wrack as it is in the most elaborate of Flowering Plants.

There is a further line of interest presented by the Algae, and especially by the Red Seaweeds. Their germs are very numerous, and they are scattered pro-
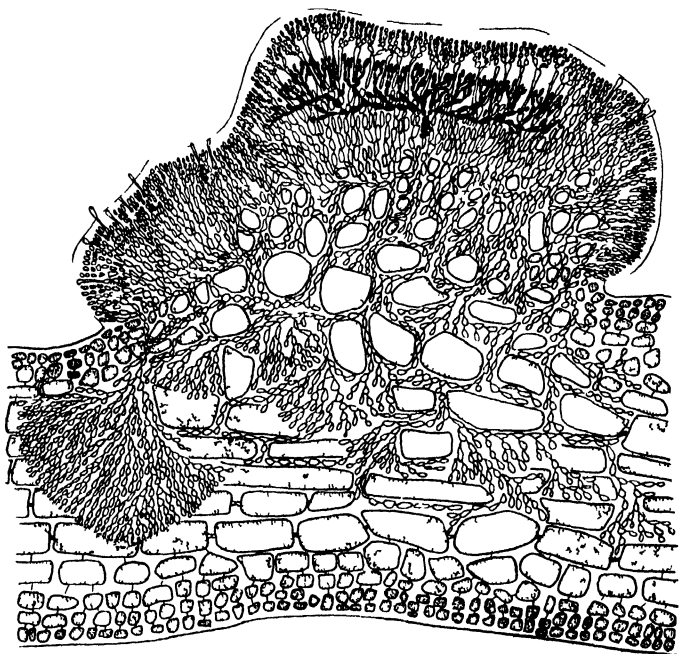
FIG. 55. A COLOURLESS ALGAL PARASITE (*Harveyella mirabilis*) growing is on *Rhodomela* mother of the Red Algae. The section is longitudinal and shows the parasite bearing a mature cystocarp, the fertile filaments of which are black. Many of the cells of the host are dotted and contain food material, those which have been exhausted by the parasite are left blank. (After Sturch.)

miscuously, germinating where they settle, whether on rocks, or wooden piles, or ships' bottoms, or on other living seaweeds. In the last-named case, a close relation is set up between two living organisms. The opportunity is given for parasitism, that is, that one of them should become dependent on the other not only for mechanical support but also for nutrition

The opportunity is certainly taken sometimes. A convincing instance is that of *Harveyella*, structurally one of the Red Seaweeds, but developed as a colourless parasite fixed upon another Red Seaweed, *Rhodomela*, which retains its colour, and provides nutrition. The tissues of the host are penetrated by the parasite, and the contents of its cells are used as food. Many other examples provide more or less complete proof that among the Red Seaweeds parasitism is now in course of being established. The special interest of this is that many of the Fungi show characters that suggest a relation with the Red Seaweeds. In particular the family of the *Laboulbeniaceae*, which are parasitic on flies and other insects, bear propagative organs similar to those of the Red Seaweeds, a fact that is the more convincing since those organs are very characteristic. Thus it would appear possible that the Red Seaweeds have supplied an evolutionary source for certain Fungi. Other Fungi similarly have sprung from the Green Algae, the opportunity having been given by such close contact with the host as is often seen in submerged plants. In fact, Fungi may actually be caught nowadays in the making; for occasionally Algae are seen to take up a habit of physiological dependence and lose their colour, with other structural changes. This is probably true enough, but the origin of all Fungi cannot be thus summarily explained. Some of them are plants of very early existence, as is shown by the evidence of the Rhynie Chert from the Devonian Period. Here undoubted Fungi are found preserved, together with other fossil plants, and they show that at that very early period Fungi must have existed in forms not altogether different from those of the present day.

It thus appears that the study of the Seaweed flora, itself composed of early plant-types, may suggest very far-reaching ideas. It throws light upon the ultimate origin of a massive plant-body, by various methods of aggregation and elaboration, from the simple filament, and ultimately perhaps from the free-swimming Flagellate ; it illustrates the natural steps taken in the differentiation of sex, and it presents us with the conception of a fungal state in the making. Truly the philosopher on the seashore has no dearth of material in that narrow belt where the fixed or " benthic " Algae grow. But if he lets his mind wander to the whole expanse of ocean, and reflects upon the myriads of minute floating Algal organisms, or " plankton," which live freely in the upper levels of the water, he will see in them a flora much vaster in extent than that of the seaweeds we see lining the shore. For them there is no limit of spread owing to the depth of water, for they need no fixed basis of attachment. This flora of invisible units is that which bears also a much greater value for Man. It forms the first link in those food-chains which by various steps find their natural end in the fish which we see in the shops exposed for sale.

CHAPTER XI

GOLF LINKS AND PLAYING FIELDS

OUTDOOR games are almost all founded on Man's skill in giving definite and precise direction to movable bodies. The Caber, the Quoit, the Bowl, and the Curling Stone have all of them forms less simple than the sphere, and they take their place in sports which have had a long history. But the most refined games centre round the sphere or ball itself, which by its form is susceptible of greater speed of movement, while its regular shape gives the opportunity for greater accuracy in its control. The essence of the game is to excel opponents, both sides reckoning not only with the laws of the game but also with the perpetually interfering forces of Nature. Gravity in particular, with its downward pull on the ball, compels our attention to the ground on which it must fall or run. The question for us will then be the part taken by the ground over which the game itself is played.

Turf is the usual surface chosen for such games ; though under difficulties of climate, or in order to gain greater precision, they are sometimes transferred to a bare and hard but carefully tended surface. The quality and the very existence of turf depends closely upon climate, soil, and the plants that compose it.

In our temperate and well-watered land we are accustomed to a close sward. But on the rock of Aden a lawn would need to be as carefully nurtured as a tropical orchid is at home. Even in Ceylon, with its insular climate, the closely mown grass-plots of Peradeniya gardens are held to be an unaccustomed sight. Putting aside such extremes in other lands than this, it may be said that the smooth lawns and playing fields of our islands are quite exceptional. Success in producing our fine turf is founded upon specially favourable conditions of climate, combined with years of skilful attention.

The introduction of the mowing machine in place of the scythe opened a new era in the keeping of lawns, and the precision of games such as cricket, croquet, lawn tennis, bowls, and golf has advanced in harmony with the closeness and evenness of its power of shaving. The surface may be compared on a large scale with that of a billiard table, over which the ball moves with accuracy. In the case of grass this depends greatly on the constitution of the turf, while the soil immediately below it has much to do with the problem of a fine-textured surface. If natural turf be used, it has to be carefully re-laid and weeded of the coarser plants ; while in the formation of new turf the seedsmen supply mixtures of the finer grasses, such as the Fescues, Airas, and Poas. The ground, if not naturally dry, should be drained and laid with a porous subsoil, such as ashes. Thus prepared, a fine turf can be obtained either naturally or artificially. So highly is a fine sod valued that bowling clubs, moving from an old green to a new site, have been known to carry away their old turf with them, to be re-laid elsewhere.

It is needless to enter into further detail in the management of carefully tended playing-fields for cricket, tennis, and other games, which require merely a closely matted and well kept turf. A much wider interest is presented by golf links, for their best features to-day are based upon the effect of plant growth in moulding the contours of the ground. The game of golf finds its natural home at the sea-side. Widespread as it is to-day inland, it was of coastal origin, played upon a sandy substratum, and the constant effort of the inland greenkeeper is to construct features which are characteristic rather of the seashore than of the midlands. However well he may carry this out, the inland course is different from the true coastal links. The contour of the surface, as well as the quality of the turf and of the sand below it, make one realise that golf at the coast is the reality and inland golf its mere shadow.

The links of the sea coast may be as various in conformation as the coast itself. The rock sculpture, which underlies the surface, gives them their primary characters. However thickly covered by sand and soil and varied vegetation, sooner or later the solid rock would be reached by boring, and it is in the inlets of the coast-line and the depressions of this rock-surface that the materials collect to form the links themselves. These may take the character either of towering dunes or of more level sand-fields. But, though often out of sight, the rocky skeleton has been the prime factor in the shaping of the links. Apart from this, their detailed characters arise from the agencies which determine the transfer and lodgement of wind-borne sand.

The sand itself consists of comminuted fragments

of rock or of sea-shells, and it is cast up by the waves upon the beach.   Thence it is liable to be carried by wind upward to the land.   Once deposited in any given position each grain, being unattached, is free to be moved again by any gust of wind, or heaped up if the wind be steady and constant. Sand-hills or dunes may be formed by the action of wind alone.   Ex- amples of this have been studied with special care in the Libyan Desert, where the wind-formed dune takes a very de- finite crescentic shape, styled a Barchan (Fig. 56).   The moulding of the wind-formed dune is commonly such that a gradual slope of 5-10 degrees on the windward side leads up to a ridge, from which the surface again falls with a slope of about 30 degrees on the leeward face.   But on our coasts this regu-

FIG. 56.—A TYPICAL BARCHAN OF THE LIBYAN DESERT. the Khurga Road dune (After H J I Beadnell F G'

larity is rarely seen owing to the variable direction of the wind.   Such dunes are unstable and apt to move. They are called white or shifting dunes, such as are seen in perfection at the Maviston Sands, near Forres.

There they slowly move onwards, enveloping whole
woods, killing the trees, and leaving their stark stumps
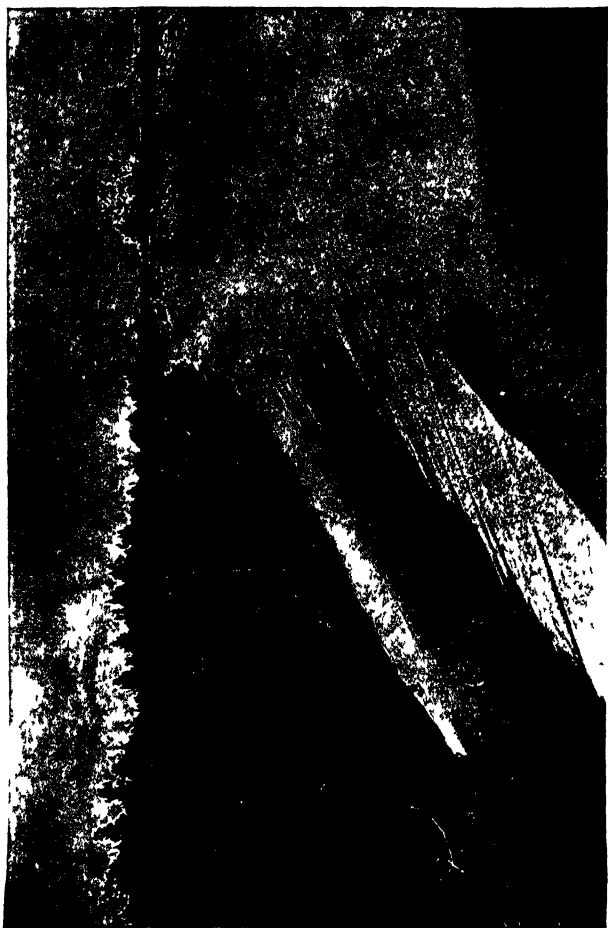
FIG. 57.—LANDWARD MARGIN OF THE MAISTON SANDHILLS, near Forres, showing a shifting dune advancing so as to envelop a well-grown pine wood The dying tree-tops are seen projecting from the sand to the right (After a photograph by H M Geological Survey for Scotland)

uncovered again as they pass on their way, driven by
the prevailing wind (Fig. 57).

Vegetation comes in as a stabilising factor on shift-
ing sand. By far the most common and effective
plant in fixing the surface is the Marram grass, or

" Bent " as it is called by golfers (*Ammophila arun-dinacea*).   It appears coarsely tufted above ground, with long narrow sharply-pointed leaves that flatten out when wet and curl up under drought, looking then like green wires.   Hidden in the sand are its long running rhizomes that are densely matted together,

FIG. 58 —A DENSE MAT OF MARRAM GRASS from which the sand has been washed away by the waves at high water so as to show the horizontal rhizomes and the roots in their natural positions, as they were embedded in the sand

and are thus a marked factor in its success (Fig. 58). They are firm and resistant like strong cord, and they may be traced for long distances threading their way through the structure of the dune, while the tip of each rhizome or bud is indurated and sharp like the point of an awl.   Leaves are borne at intervals, and in the axil of each a bud with fresh leaves and a tuft of roots may arise (Fig. 59).   The rhizomes may grow

horizontally, or they may turn upwards, emerging to form a new leafy shoot with shortened internodes and tufted leaves. Such tufts again hold the wind-blown sand : meanwhile the grass growing upwards offers fresh shelter, and higher layers of sand are
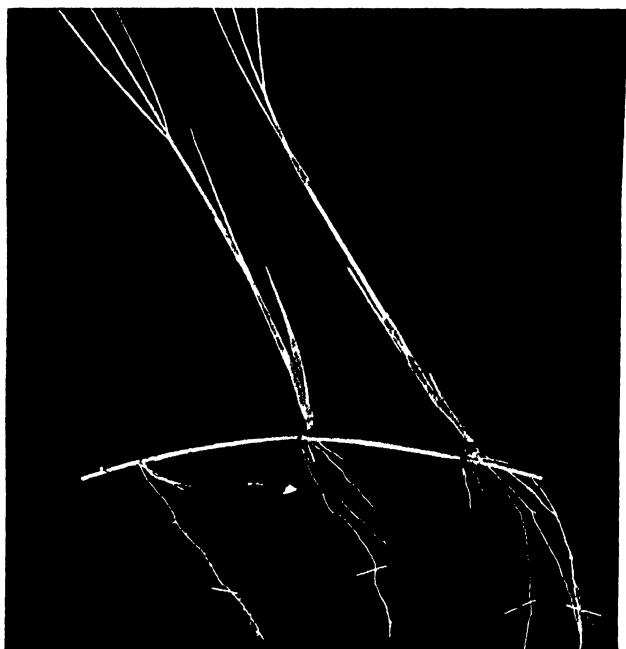
FIG. 59. A HORIZONTAL RHIZOME OF MARRAM GLASS showing three nodes from which roots rise. From two of them leafy buds have grown upwards through the sand having sprung from the axils of leaves now decayed. The arrow points towards the apex of the rhizome.

caught. In fact the dune grows with the grass that stabilises it. The grass is thus highly adaptable to its circumstances ; this, combined with the peculiar structure of its leaves, makes it before all others the leading stabiliser of shifting sand, and a real factor even in the growth of the dune. Other grasses may take their part, but the Marram grass excels them all.

The shifting dune once stabilised by sand-binding
plants, the spaces between these are soon occupied
by other Flowering Plants of low stature, together with
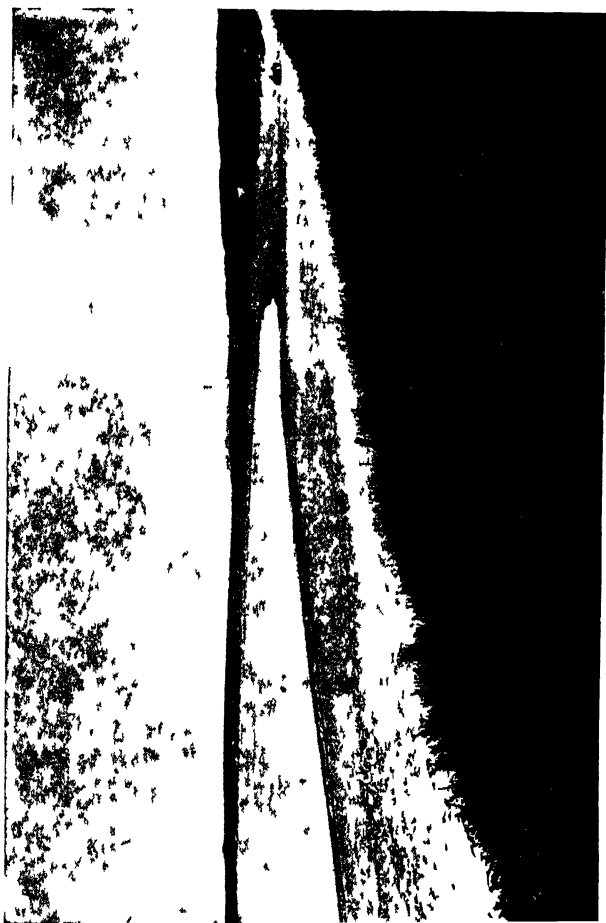
FIG 60 SAND DUNES IN DUNNET BAY (CAITHNESS The rounded coast line is characteristic of dune
formation The grass covered dunes rise boldly from the level of the beach (After a photograph by H V
Geological Survey for Scotland)

Mosses Lichens, and some Fungi Some of the most
effective plants in the transformation of the shifting
dune to the so-called Grey Dune are woody, such as
the Creeping Willow (*Salix repens*) with its prostrate

twigs, the Burnet Rose (*Rosa spinosissima*), and the Rest Harrow (*Ononis spinosa*) ; and so what is at first an unstable formation is compacted till it acquires a settled character. But though dune-formation may slowly progress seawards, it is constantly checked by the action of the waves at high water in stormy weather. Consequently they are commonly found to run in concave curves between headlands, and they round off the indentations of the coast line. Like the softer tissues of the animal body they mould themselves upon and round off the configuration of the harder skeleton within (Fig. 60).

There are thus three factors which share in the prime construction of sea-side links. The first is the rocky skeleton which defines the broad features of outline. Secondly, there are the plants that act as dune-builders, by whose means the moving sand is temporarily held, or even aggregated into heaps of various form ; and thus are initiated those swelling contours which give so much of their character to coastal courses. Thirdly, there is the skin of mixed vegetation which follows, giving permanence to the otherwise inconstant dune. Jointly these factors supply that raw material from which the fully protected course may be produced (Fig. 61). The further agents are animals and Man. Of animals the most effective are rabbits and sheep : the former nibble down the coarser growths. They crop the sward to an even velvet, stiff it is true in the pile, but short and smooth such as the golfer loves. So close is this thin film of turf to the underlying sand that as a ball falls upon it from a long shot the sound is sometimes musical, like the ringing of a bell. But the holes and scrapings of rabbits are a perpetual trouble, leading not only to

cupped lies but to possible " blow-outs," the parents
of bunkers.   The close nibbling of sheep is usually
preferred as being clear of this disability, though it is

FIG 61 — THE SO CALLED FLOOD TAWS IN REAR OF THF SAND DUNES OF KEISS LINKS EAST COAST OF CAITHNESS Patches of *silix repens* are seen rising from the lower herbage Thus scene is an example of the raw material of coastal links   (From a photograph by H M Geological Survey for Scotland)

not so close as that of rabbits.   Both agents frequently
work together on the native links ; but the rabbit is
there on sufferance, while the sheep are penned upon
the links on purpose.

Such is the scene upon which the greenkeeper has to exercise his skill, whether constructive or destructive. The raw material of the links is an ordered balance of Nature, and he enters it as a disturbing influence. With his scythe, his mowing machine, and his roller he does in mechanical fashion what is so much more picturesquely done by the free agencies of Nature. He fixes the " blow-outs " as bunkers, often arresting the effect of the wind by lines of railway sleepers or piles of sods. He opens out new and artificial hazards, placed as intentional traps. He cuts away Heather and Creeping Willow, trims down the bents, and reduces the greens to the quality of the best-kept lawn. He may by these means produce a course on which a record score may be lowered ; but to the naturalist he seems to upset the balance of Nature, the observation of which is to him one of the keenest delights of the links. Though we may regret the modification or even the loss of the natural hazards, we may still remember with satisfaction that the changes that the greenkeeper produces do little to modify the main contours of the ground. These, with their irregular undulations, their arbitrary slopes and towering heights, are the true product of natural forces, and a determining factor that has influenced their origin and their form more than any other is vegetation. The individual plants that shaped the dunes may have passed into natural decay, or have been swept out of existence by the modern greenkeeper ; but still their record remains registered for ages in the undulating surfaces of the links.

Though outdoor sports are a special feature of recent times, the ancients had already devised games that centred round the freely moving sphere, and

we know that the practice of such games continued
through mediæval times.   But no period of history
can compare with the last half-century in the increase
in the pursuit of ball-games, and no modern race can
compete with the British in fertility in devising them.
The cause of their great expansion in recent years may
be found in the massing of population upon limited
areas.   There arose in consequence a need for the
pursuit of recreation and of health itself by means
different from and more artificial than the chase.
The primitive duty, and in its later developments the
sport, to kill, becomes impossible in crowded districts ;
but still the necessity for bodily exercise remains,
while more than ever mental diversion becomes an
insistent need under the stringent conditions of urban
life.   It is the ball-game that gives the best oppor-
tunity for bodily exercise, in fresh air and upon a
limited area of ground.   It also supplies that whole-
some rivalry that promotes good humour and good
fellowship.   Overcrowding has been the foster-mother
of ball-games to-day.   They must needs prove a very
real factor in protecting the human race from some of
the natural consequences of industrialism, by exer-
cising the cramped body and diverting the over-
strained mind.

CHAPTER XII

THE FLOWER GARDEN

PRIMITIVE Man, like the savage of the present day, simply took what Nature, bountiful at times but at others grudging of her gifts, was willing to afford. Before the era of cultivation her supplies were apt to be uncertain, and their adequacy depended upon Man's own initiative in collecting what he required. This method may possibly be sufficient so long as the needs are simple, the population sparse, and the productive area large and easily accessible. Such primitive conditions favour a nomadic rather than a settled habit of life. But it is only under kindly circumstances that a growing population can be supported by these means. One of the earliest steps towards civilisation, as shown by ancient documents, has been the cultivation of certain plants selected for their use. The practice of agriculture necessarily attracted mankind to a stationary habit, and certain peoples adopted early a communal tenure of land, which still has its relics traceable in modern life. The general tendency, however, has been towards individual freedom of effort. It is in the flower garden that the individuality of man is specially apparent in his cultivation of the soil. The primary needs of life were food, shelter,

clothing, drugs, etc. After these had been supplied the aesthetic sense would suggest also the cultivation of flowering plants selected for their beauty and scent. The field and vegetable plot probably claimed first the attention of the tiller of the soil, while the flower garden will have followed as a later step in the civilisation of Man. Never, probably, in the history of the world has it taken so important a place in the common life as it does to-day. The ideal towards which an ordinary flower garden is directed is the supply of a continuous succession of blooms throughout the year, thus securing *ver perpetuum*, or everlasting spring, as Bacon called it. But the perfection of those blooms according to certain set standards, sometimes of a highly artificial character, is a secondary ideal, apt to be elevated by enthusiastic specialists into a prior place.

The most primitive horticulture no doubt consisted in transplanting into the flower-plot the choicest wild flowers of the open country, eked out by others introduced from abroad. Relieved from competition and with the best advantages of soil and aspect, together with selections of the best varieties, improvement of type might well be expected in such directions as Man's aesthetic sense demanded. These were in fact the simple methods of the early horticulturists, and they still reign in the rock garden and go far to people the herbaceous border. The modern garden with these as its leading features has more in common with the botanic garden, and with Nature herself, than that of Victorian times, with its weary reiteration of Pelargoniums, Calceolarias, and Lobelias. These secured, it is true, a sustained blaze of colour, but at the sacrifice of variety. The plants of the rockery and

herbaceous border are more varied, and the times of
their flowering better spread. The blaze of colour
may be less, but the blooms themselves preserve more
nearly their natural form, colour, and scent. They
are, as a rule, efficient reproductive mechanisms, and,
provided the suitable pollinating agent be present,
they commonly produce normal seeds.

Horticulture has the general effect of diverting the
cultivated stock away from the original type by intro-
ducing " improvements " upon it. The triumphs of
the modern flower-show suggest how far the higher
horticulture has progressed beyond merely raising in
quantity the plants of the open country, whether
native or foreign. They bear witness to the skill of
the plant-breeder as well as of the cultivator in creat-
ing novelties by hybridisation and by selection among
the offspring. These methods have been carried so
far that the original parents are apt to be lost to sight
or even to memory. Often they survive only in
botanic gardens or in their native homes. Who can
pick out from our shrubberies the original *Rhodo-
dendron ponticum*, or who is really well up in the
parent species of our Fuchsias or Chrysanthemums ?
The original stocks may at times be collected and
grown on the occasion of some centenary, showing
how far the modern forms have diverged from the
source. But however great the divergence may be,
the horticulturist has worked and must always work
within the limits of variation of the plants cultivated,
growing, as they always must, according to the im-
perative laws of heredity and plant physiology. He
finds his chief scope in relation to the reproductive
processes, thus catching Nature in her most exuberant
mood. But in securing the object he frequently upsets

the normal production of seed. He is then forced
to fall back upon methods of vegetative propagation.
Thus, by means of cutting, grafting, and budding he
continues the specially desired strain. The botanist,
seeing this, will not measure horticultural success
merely by the floral display produced. He will see
in it the result of an effort towards an ideal, subject
the while to limitations imposed by Nature herself.
Frequently the horticulturist will be found to have
taken advantage of methods already adopted in the
evolution of the plants he works upon. A familiar
example will illustrate this.

A great feature in the horticulture of the past has
been the mere securing of colour-masses, and a com-
mon source of this has been the " doubling " of flowers,
that is, the multiplication of petals. The form of the
flower and, in great measure, its functional capacity
have been sacrificed for mere show. The lust of the
eye of the gardener has spoilt the pride of life of his
charges. And yet what we see as the result simply
carries out extravagantly a change which Nature her-
self has initiated. The view is very widely held by
morphologists that the evolutionary origin of normal
petals has been in many if not in all flowers, by con-
version of the outermost stamens into broad expanses
of colour ; these serve the biological purpose of attrac-
tion to insects, the pollinating agents. The stamens
thus transformed sacrifice their propagative function,
and in so far as they do this the flower may lose in
propagative capacity, though it gains in attractive-
ness. Gardeners use this transformation as the basis
of their artificial " doubling," which usually consists
in the further conversion of stamens into petals ; and
naturally those flowers in which stamens are normally

numerous lend themselves most readily to the change,
e.g., Peonies, Roses, Cherries, Camellias, Begonias, etc.
But the transformation of stamens to petals also occurs
sometimes in flowers with a definite number of parts,
e.g., Petunia, Narcissus, and Snowdrop. Such a change
of function is not, however, the sole source of added
petals : Von Goebel has shown that extra parts—and
even extra cycles of parts—may be interpolated be-
tween those normally present. This is well seen in
some Fuchsias. The effect of it all is, while adding
to the showiness of the flower, to decrease its propa-
gative efficiency, partly by clogging the mechanism,
but greatly by diminishing the supply of pollen. The
point of complete absence of pollen may even be
reached with sterility of the flower as the probable
result ; as in doubled Stocks. What is thus seen in
the individual flower may also appear with like effect
in the whole truss of flowers, or inflorescence. Every
Daisy, which is a head composed of many small flowers,
shows an initial step in this sacrifice of efficiency for
show. Each white ray is a flower enlarged at the
expense of its stamens, which are absent. The wild
Corn Flower owes its colour-attraction to the ring of
blue florets round its margin, and they have no func-
tional reproductive organs at all ; these have been
sacrificed so as to promote the showiness of the whole
head. In various degrees such concessions may be
seen in other examples of the Daisy Family, a gain in
attractiveness of the whole head having been purchased
by steps towards sterility of the individual flowers
that compose it. The same may be seen also in other
families : for instance, the natural forms of Hydrangea
among the Saxifrages, and of the Gueldres Rose
among the Honeysuckles, have already taken the first

FIG 62 — THE GUELDRES ROSE (*Viburnum Opulus*) *A* the natural state
B the sterile truss of gardens (From P Groom)

steps by a like sacrifice of the marginal flowers of
each truss, which are showy but sterile (Fig. 62, *A*).
The gardener, encouraging by cultivation the degra-
dation of the rest, produces masses of flowers that are
useless for propagation. However large and attractive
these trusses may be, they are sterile.   This is indeed
the *reductio ad absurdum* of horticulture (Fig. 62, *B*).
But Nature does not allow the gardener to have it
both ways. By increasing their showiness he risks
or even loses the propagative power of his flowers
by seed, in fact he prevents the very end which it
was their original function to perform. This threat-
ened sterility if carried into full effect would lead
to extinction. The death of the individual would
terminate the race, were it not for the methods of
vegetative propagation, which are Nature's remedy
and the gardener's opportunity.

The most powerful weapon in the hand of the hor-
ticulturist is hybridisation, and it has been freely used
by him, thus adopting again a method which Nature
herself supplies. So far as qualities can be transmitted
from parent to offspring, the mechanism of fusion
of the sexual cells, or gametes, offers the natural
means for their transmission.   The intercrossing
parents, differing within due limits from one another,
may by fusion of their gametes produce offspring that
shares in some degree the qualities of both. Such
offspring is called a hybrid.   There are many grades
of difference between parents which are capable of
intercrossing.   Minute differences exist between all
individuals, even those nominally alike : greater
differences may be distinguished as strains, varieties,
species, genera, and so on. By gradual steps there
may thus be transition from the similar to the strongly

dissimilar. Within certain limits the dissimilar can
breed together ; for instance, individuals, strains, and
varieties commonly interbreed. Sometimes species
and even genera can produce offspring together. The
bi-generic crosses of certain Orchids artificially pro-
duced are a well-known feature of horticultural shows.
The seeds that result from crosses between distinct
parentage may germinate, and the resulting hybrid,
sharing the main qualities of both parents, is some-
thing different from either of them. Moreover, there
is apt to be a wide latitude of variation in the hybrid
progeny, and the horticulturist selects those which
suit his taste or requirements, rejecting the rest. By
such intercrossing and selection the gardener has in
his hands a creative weapon, which he has not been
slow to use ; and flower-gardens are full of the results.

But here again, as already seen in doubling, undue
interference with Nature commonly brings its own
nemesis. The shadow of sterility dogs the steps of
hybridisation ; many hybrids are incapable of pro-
ducing germinable seeds. Those produced from
crosses between parents not markedly different may
germinate ; but where the parents are strongly dis-
similar, either there is no offspring or it is apt to be
itself sterile, as is the mule, which is a hybrid between
the horse and the ass. A limit is thus set upon the dis-
tinctness of parentage. Nature intervenes by the
barrier of sterility to prevent promiscuous inter-
crossing of parents beyond certain prescribed limits.
Again the horticulturist is brought up against a dead
end. He has used the means of sexual propagation
supplied by Nature herself, but he is prevented by
the sterility of the offspring from abusing it. His
sterile hybrids may give him pleasure in his garden,

but they must be artificially propagated there by
vegetative methods, since they bear no seeds.   If
by chance they escape beyond the limit of his care,
as a rule they fail to maintain themselves under the
competition they meet with in the open country.
Even in the garden they must be propagated
artificially if they are to retain their qualities or,
indeed, to maintain a bare existence.   Thus the two
avenues of " improvement " most used in horticulture
lead towards the practice of vegetative propagation
as a useful or even as a necessary refuge from failure.

In Flowering Plants vegetative propagation consists
in the independent establishment of buds.   A bud
produced either in the normal axillary position, or
induced at some spot not usually so occupied, may
be separated from the parent plant and stimulated
to grow independently of it.   A runner of a Straw-
berry or a layered shoot of a Carnation, a tuber of the
Potato or of the Artichoke, separated from the parent,
will each grow into a new plant if the conditions be
favourable ; and being a part of it produced by vege-
tative growth alone it will keep accurately the quali-
ties of the parent.   The Carnation will have the same
colour and scent, the Strawberries will have the same
flavour, and the Potatoes the same power of resisting
disease.   It is but a step from such simple methods
to those of cutting, budding, and grafting.   In the first
a shoot is removed from the parent plant bearing one
or more normal buds, and it is kept under such cir-
cumstances of heat and moisture as to induce root-
formation from its base plunged in the soil.   In the
second buds, or shoots bearing buds, are inserted not
in the soil but with their living tissues in contact with
corresponding tissues of some related plant (Fig. 63).

The two living tissues then unite, and their junction
is such that the woody column of the stock provides
the stream of water and salts to the alien bud, while
the latter carries on its own nutrition by chlorophyll
in the light. The bud or graft retains its original quali-
ties ; but according to the vigour of the stock it may
mature earlier in the season, and the flowers or fruits
may be more profuse than would happen if it were

FIG. 63.   METHOD OF SHIELD BUDDING OR CUSHION GRAFTING
is practised in Roses   To the left the necessary incisions, with the
outer tissues separated at the cambium layer ; in the centre the bud
and leaf base attached to a shield of living tissue of the parent   to
the right the shield in its place and bound up   (After Figuier)

upon its own root. Indefinite multiplication of a
given strain or variety is thus possible without loss of
quality ; but besides this, time is also saved, for it is
much quicker to insert a graft or bud upon an estab-
lished stock than to raise an equally strong plant from
a cutting (Fig. 64.)

Grafting sometimes leads to bizarre results, at first
sight difficult of explanation.   A well-known example
is *Cytisus Adami*, a Laburnum which bears on some
branches purple, on others yellow, flowers.   Another
is to be seen in a Beech, some branches of which bear

leaves like those of the ordinary Beech, while others
have leaves deeply cut. Such plants are " chimaeras,"
which have probably been produced from grafting.
They are not hybrids in the true sense of the word,

A   *B*

FIG. 64. — *A*, *B*, ILLUSTRATIONS OF GRAFTING. *A* cleft grafting,
where a suitably prepared twig, or ' scion," of the plant to be propa-
gated is inserted into a cleft in the living tissues of the " stock."
B approach-grafting, or marching, where suitably prepared surfaces
of the " scion " and " stock " are brought into contact while both
plants remain rooted till union is complete, when the base of the
scion is cut away. (After Figuier.)

for it appears that no nuclear fusion has taken place.
Buds produced from the callus where graft and stock
unite have been formed by a mechanical coalescence
of tissues from the two separate parents : in the case
of the Laburnum the one was the ordinary yellow, the

other the purple flowered. According as the one tissue or the other contributes to a branch or bud, it will bear either yellow or purple flowers, or the two may even be intermingled. And so also with the Beech. Such chimaeras are in fact in a sense composite organisms.

The philosopher, wandering through a modern flower garden or flower show, sees in the brilliant triumphs of horticulture many beautiful, as well as instructive aspects of plant-life. For him a special interest will lie partly in the selection and use by the gardener of the choicest natural species and varieties, these still retaining in the main their original characters ; he will mark the adjustment of the conditions to the requirements of each plant, and the degree of the cultivator's success. This is the interest specially developed in the rock-garden and the herbaceous border, or, better still, in the wild garden itself. Partly, the interest will be one of potentialities. He will trace how far horticultural skill can stretch the natural plant from its native state towards the ideal show point, by culture crossing and selecting, and will note at what stage Nature steps in with a firm negative. Whichever of these or other lines of thought may be in the ascendent in his mind, he will see in the horticulturist a man of ideals, struggling to realise them, but like any other artist held in by natural limitations ; some of these may be overcome by skill and perseverance, while others appear to be absolute.

CHAPTER XIII

THE KITCHEN GARDEN

A WELL-KEPT kitchen garden is a delightful spot. Its owner's prime object is to secure, by regulation of its size and by the method of the cropping, a sufficient supply of vegetables and fruit for his household throughout the year, and often its arrangement is designed solely for this end. Though such a garden bears its utilitarian character upon its very face, it nevertheless possesses a high degree of scientific interest : for ages of earlier cultivation have been required to produce the results which we see to-day, while practical advances to still greater efficiency are even now being made. But it is a common practice, especially in private gardens, to add an aesthetic touch to the utilitarian plot by laying out herbaceous borders along the main walks. However we may value these added beauties, they need not detract from the satisfaction of seeing well-grown vegetables, for these show plant-structure in its most redundant mood. They represent a wonderful achievement of horticultural art, though this must always play within the limits of natural organic development. They prove again how vastly Man may modify the form and proportion of species. Much of his present

success has depended upon the selection by his prede-
cessors of plants capable of responding to his skill.
The more recent successes should not obscure our
sense of the prophetic vision possessed before the so-
called scientific age, for that must have formed the
basis of later horticultural practice.

The ideal shape for a kitchen garden is a parallelo-
gram with its length running approximately east and
west. It should slope gently to the south, and be
walled on three sides, but remain open to the south,
so that none of the southern sun shall be lost. The
boundary in that direction may even be a sunk fence.
The garden walls may be backed by a wind-belt of
trees on the north, east, and west. The aspect may
with advantage be slightly west of south. The effect
of this will be to catch a full share of the afternoon
sun, which, falling upon it during the warmer hours,
will leave the garden better stored with heat to en-
counter the cold hours of night. More especially is a
slight deviation to the west important during the days
of flowering of fruit trees trained on a south wall. A
late spring frost followed by a sudden morning thaw
may at that critical moment ruin the year's crop.
The chief risk is then the sunny morning. If the
garden faces slightly west of south the direct sunshine
on the wall will be delayed, and the slower rise of
temperature will diminish the risk. Service walks
may describe a smaller parallelogram within the boun-
dary walls, while the central plot may be cut into four
quarters by broad walks of gravel or of grass. Her-
baceous borders backed by low espalier-trained fruit
trees may fringe the walks, while the four inner plots
will be the chief productive ground for the kitchen
crop itself. The beds immediately under the wall

facing south may be kept as seed plots, or used for early vegetables and for aromatic herbs ; these, and especially the last, requiring all the sun they can get.

The immediate object of the vegetable garden is to obtain in the shortest possible time the largest possible quantity of succulent plant-tissue with the least proportion of fibre. The crop must therefore be taken young, before the fibrous tissues, so necessary for strengthening the plant and for the conduction of materials, shall have developed, and the plants have become " stringy." The ideal was the same for primitive Man as for ourselves, and it certainly influenced his choice of the inmates of his vegetable patch. The early cultivator, looking round upon the plants of the country, would be sure to select those already in some degree suited to this purpose by their mode of growth. His choice would fall on those naturally succulent. These are specially found among the dwellers along the sea-shore, or in very dry exposures. In particular, material for his skill in cultivation would be found among those plants that are biennials, for these so often store food in their first season of growth, ready for the sudden demand of flowering and fruiting in the second. A glance round any kitchen garden will show that these have been the sources of most of the plants that it contains. The origin of many of them was coastal, while not a few are biennials. But when we compare, for instance, a well-grown Cabbage with the original species growing on the shore, we at once see how far the cultivation of ages has altered the type, and fitted it for the culinary uses of Man.

A tour round the beds will show how greatly the kitchen garden has depended on such sources as those mentioned. First will naturally come the whole group
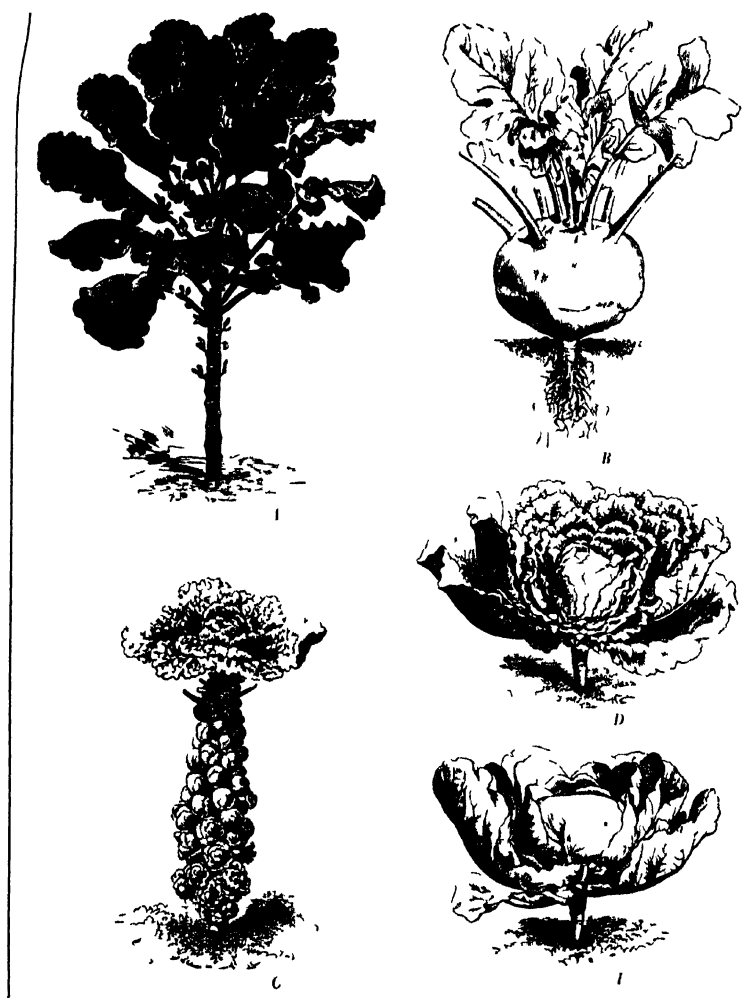
FIG. 6.—RACES OF *Brassica oleracea* 1 showing how greatly the form has been modified under cultivation 4—the common blue cabbage B kohl rabi C the Brussels sprout D=Norwegian savoy 1 (center kraut) hundred weight cabbage (After Vilmorin)

of cultivated forms which centre round the names Cab-
bage and Turnip.   According to the Kew Index these
are all referable in origin to two Linnaean species,
Brassica oleracea L. and *Brassica campestris* L., though
there has been some difference of opinion as to the
actual sources.   As a matter of fact, the history has
been lost in the past, for these plants have been culti-
vated from very early times, and it is only by compari-
son of the now diverse garden types that they can be
referred to their probable origin.   Examination of them
shows how great a plasticity of form cultivation may
induce in favourable instances (Figs. 65, 66).   Among
the Cabbage-forms few would recognise the walking-
stick Cabbage of Jersey, the Kohl Rabi of Germany,
the Brussels Sprout, the Welsh Cabbage, Drum-head
Cabbage, Curly Kale, Cauliflower, and Broccoli as
closely akin, if they were examined only from the point
of view of their curiously divergent vegetative state.
But when flowering supervenes in the second year,
their essential similarity is manifest in the great uni-
formity of the flowers.   The vegetative phase in the
life of all of these plants has been strained, by long
cultivation and selection, into extreme and specialised
channels.   They have been bred and selected so as to
yield large masses of succulent tissue in various forms
and at different seasons of the year.   But the Cab-
bages have all been referred to an original stock,
Brassica oleracea L.   It is a smooth-leaved glaucous
plant that may be found not unfrequently growing
on cliffs by the sea.   On the other hand, Turnips
have been referred in origin to a distinct Linnaean
species, *Brassica campestris* L., which is distinguished
by having hispid leaves (Fig. 66).   It is, how-
ever, still doubtful what relation the Turnip bears

to the Swede in point of their derivation from wild
sources.
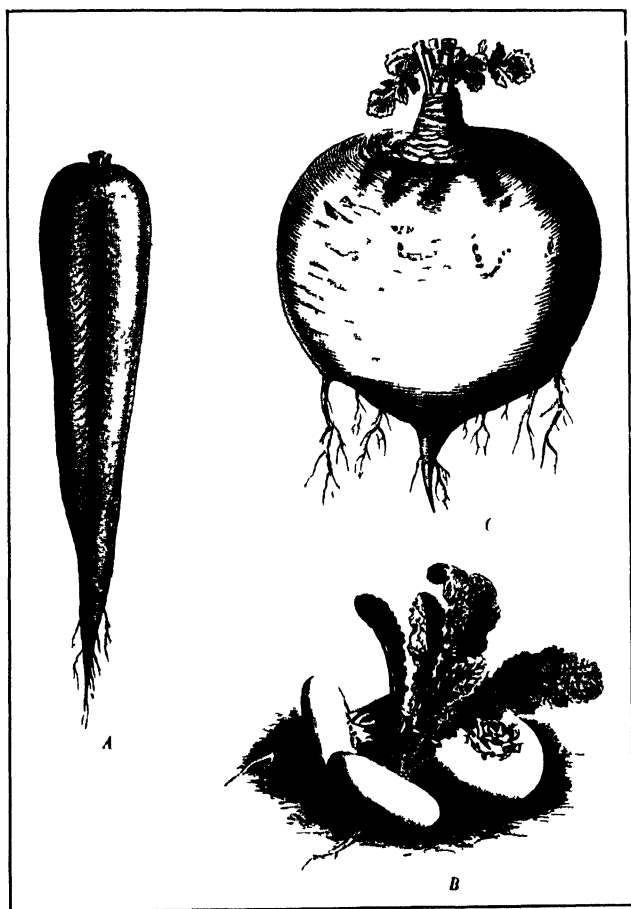
FIG 66   CULTIVATED RACES OF *Brassica campestris (I rapifera*
Metz) THE TURNIP   (After Vilmorin)

Other garden vegetables of coastal origin are the
Seakale, Spinach, Beet, Carrot, Potato, and Asparagus.
The Seakale is occasionally found native on our sandy
sea-shores, not markedly different from the garden
plant whose blanched shoots yield one of the most

delicate of spring dishes. The rest have diverged further from their several sources. The Beet is not unfrequent on coastal rocks : but in the wild plant, though the leaves are succulent, the root is dry and fibrous. The same is seen in the Carrot, the original form of which is common on sandy soil, especially near the sea. The Potato is found wild on the Chilean coast, and especially on the island of Chiloe ; but there the tubers are only about the size of hazel nuts. The original form of the garden Asparagus still survives locally on our own shores, giving its name to Asparagus Island, off the coast of Cornwall ; but its young shoots would provide a very meagre and fibrous dish. Every one of these garden vegetables appears to have diverged far from the original type, not so much in the flowers or fruits as in the development of the vegetative phase. The prize potatoes of our shows are very different from the small tubers of Chiloe. The succulent root of the Beet, with its high per- centage of sugar, especially when selected for supply- ing the sugar factories with their staple, is a very different thing from the dry-rooted herb of our coastal rocks. The prototype of a bundle of fine French- grown Asparagus would hardly be recognised in the meagre rhizomes of Asparagus Island. But in each example the relatively fleshy habit, inherent in more or less degree in plants which grow in brackish soil, and in reach of the salt spray, has given the initial opportunity, and this has been improved upon through long ages by the horticultural methods of Man.

Passing now from the consideration of the vegeta- tive development, the second opportunity presented to the primitive gardener lay in the storage-habit : that is, the laying aside of food-material gained in

one season for the purpose of the next. This is not uncommon in coastal plants, and it goes frequently with a biennial life where flowering and fruiting follow on the vegetative activity of a previous season, as in the Cabbage, Turnip, Lettuce, Carrot, Parsnip, Salsify, Beet, and Onion. Often, however, the storage may be a feature in perennial life, as it is in the Potato, the Jerusalem Artichoke, and in the tuberous Stachys. The primitive storage in parts often only slightly succulent and still more or less fibrous in the original species, has been seized upon and developed to high degree by the horticulturist, as shown in the modern cultivated forms. It thus appears that the two chief sources of the soft and edible tissues of the modern vegetable garden have been the succulence of marine plants, and the storage-habit of biennials and perennials. Such succulent vegetables as those mentioned are usually cooked before they are eaten ; but some are eaten fresh as salads. In Elizabethan times the young and tender shoots of many plants, native and introduced, were used as " sallets." Some of them, such as Dandelion, Chicory, and Lamb's Lettuce are still occasionally seen ; but the salads of the present day have settled down to a stereotyped and restricted range, and thereby lost greatly in their interest.

These paragraphs by no means exhaust the stock of the Kitchen Garden. A whole section of its products are of the nature of fruits, such as Peas, Beans, Cucumbers, Marrows, and Tomatoes. The question is sometimes asked whether these are fruits or vegetables. Such difficulties arise from the inaccurate use of words. All fruits being parts of plants are vegetables in the most general sense of the term ; but this

is not its kitchen sense. Though even the Marrow when cooked and brought to the table in the course of dinner ranks as a " vegetable," yet its close relative the Melon, appearing in more delicate company at dessert, is ranked as a " fruit." But the terminology of the kitchen, which is apt to make its way even into the dining-room, is not scientific. In point of fact both are fruits in the stricter sense, as are all parts developed from the pistil of the flower. In these parts the plant is apt to concentrate its nutritive resources for the good of the offspring. This is conspicuously so with the " Legumes," and whether we take the young fruit as a whole, as in French Beans, or the young seeds only, as in Pea s or Broad Beans, the concentrated food intended for the progeny is made our own. Other fruits will form the subject of later articles, which will deal with Dessert Fruits and Cereal Grains.

Scientifically, the most impressive feature of a Kitchen Garden is not merely the actual size of the plants grown or the masses of succulent and nutritive tissue free from fibrous strands that they produce ; it is rather the degree of their divergence from the wild species, at least in cases where their origin is known. How is this divergence to be regarded in relation to Descent ? A clear indication is given by the fact that if garden varieties escape from continued selection and cultivation they revert in their characters towards the original source. In no instance has a highly improved strain established itself in the open and kept its characteristic features. This at once indicates that " improvement " is a phenomenon of " fluctuating variation." By this it is meant that the propagative cells are not so affected by the " improvement " as to have

become themselves altered in their essential consti-
tution. If they had been, the change might have
been expected to have been permanent. There ap-
pears to have been by continued selection and culti-
vation a stretching of the type to an extreme from
which it reverts so soon as the influence of the horti-
cultural art is absent. The divergence from the normal
ancestor has not been fixed indelibly upon the pro-
pagative cells of the improved race.

The methods of horticulturists, by which improve-
ments have been secured, have altered as time went
on. Originally a number of the best individuals were
selected from a mixed population ; these were then
grown together under favourable conditions, and used
as a source of propagation. This so-called mass-
selection is, however, an imperfect means of better-
ment, for the selected parents cannot be of uniform
sample. Consequently in the very first generation
many of the progeny fall short of the standard ; they
will show reversion towards the average. Such general
improvement as appears to be secured by mass selec-
tion has probably depended on the accidental in-
clusion of one or more pure lines of a high standard,
and the progeny of these keeps the average high. It
was probably in this way that all the earlier horticul-
turists worked, with results that were quite as good
as could be expected from so imperfect a method, but
improvement so obtained would be relatively slow.

In recent years the pure-line-method has been in-
troduced. It was first practised on wheat by Mr.
Shirreff of Athelstaneford ; it was then adopted by
Vilmorin, of Paris, for various garden vegetables, and
has been elaborated by Johannson and by Nilsson, of
the Swedish Experiment Station, for crops generally.

The method consists in growing the progeny of a single self-fertilised individual, and continuing this through successive generations, selecting at each step the best individuals. The result may be an improvement, but still the progeny are liable to reversion if they escape from selection and culture. Thus the result is not permanent, any more than with ordinary improved vegetables. It is believed that here again the improvement does not involve any fixed change in the reproductive cells. The advantage which the pure-line-method brings is the rapid establishment of a relatively uniform stock representing the best type attained, with even the possibility of an improvement upon it.

Thus the Kitchen Garden may be regarded not merely as a means of every-day supply of articles essential for a healthy diet : but it may also serve as a museum illustrating how far the horticultural art can stretch the variability of certain natural species : moulding them by selection and cultivation to the required model, and altering not only their form but also their nutritive content. Yet still the gardener is compelled to play within the limits of natural plant-development, while the special features that he prizes depend for their maintenance upon his own continual care.

CHAPTER XIV

DESSERT FRUITS

WHEN the epicure sits down to his recherché dinner
he little thinks that he will begin and end it like a
primitive savage. Yet so it is : for he will begin with
oysters presumably alive, and he will end it with fruits
also alive. Both are uncooked, as were all the meals
of the savage before the use of fire. We need not
dwell here upon the state of the oyster as it is pre-
sented to us on its open shell, or canvass the question
so often asked whether it has sensation, and, if so, on
what scale. But the question whether or not life still
exists is equally suggested by all raw salad-plants
on the table, and still more by the fruits that gladden
the eye during dinner and soothe the palate at dessert.
Few of us think of them as living things. But so they
are, even the Filberts, Walnuts, and Almonds, perhaps
the very stones that alloy our pleasure in the finest of
Raisins ; nor can it be safely asserted that the little
hard and brittle seeds, or more correctly nuts, of the
dried Fig are dead. They may also be still alive.

But why this doubt ? Surely it should be easy
enough to tell whether such objects as these are alive
or dead. We should, however, remember how Zophar
said to Job, " Canst thou by searching find out God ? "

In like manner even the use of the microscope may
still leave us uncertain whether the plant-cell we
examine by its aid has or has not the supreme gift of
life.   It is Divine manifestations that bring convic-
tion to the mind, and it is in the manifestations of
life, its activities and the changes that attend them,
that the proof is to be found whether a cell or a whole
plant is alive or not.   Does it grow ?   Does it move ?
Does it change chemically ?   Does it breathe ?   These
positive signs, so easy to detect when life is active and
the changes brisk, may often be in apparent suspense.
Life may be toned down to a state of dormancy in
which changes are so slow as to raise the doubt
whether it be not actually extinct.   In all the nuts
the question seems a very open one.   They may be
regarded as the most familiar examples of living plants
in a cataleptic state, almost hermetically sealed in
their protective shells.

On the other hand, in soft fruits one is well aware
of changes progressing, sometimes very rapidly.   The
Pear with its traditional half-hour of super-excellence
or some say five minutes, before which it is unripe
and after which it begins to be " sleepy "– is merely
a marked example of what happens in all mellowing
fruits.   They are all alive, and are all undergoing
changes, leading to a climax of ripeness, after which
they are peculiarly open to those attacks the result
of which we summarise in the word " decay."   The
transit of Bananas from the West Indies gives a good
illustration.   The arrangements are all made so that
the fruit shall be delivered to the market in a state
of approaching ripeness.   The Bananas are cut green,
long before they are ripe, taken on board, and stored
in bins in chambers chilled to about 56 degrees or

60 degrees Fahr. Then follows a race between the ripening process and the delivery. During the voyage the ripening, retarded by the low temperature, progresses slowly. There is active respiration as in all living tissues. Oxygen is taken in and carbon-dioxide is given off. In fact, a process of slow combustion goes forward with a consequent rise of temperature. If the arrangements are perfect, the process of ripening is so controlled that the fruit is delivered on arrival just as it begins to assume a yellow colour, and to develop the flavour of the ripe Banana. But sometimes a bin will "take charge" physiologically. Active respiration will raise the temperature unduly among the crowded bunches, which warm one another. Ripening is hastened, and a whole bin may, anticipating the market by a day or two, either arrive over-ripe or have to be pitched overboard. The risk of this is, however, diminished in the case of Canary Bananas, for their bunches are packed separately in crates, and so do not heat one another to the same extent.

This is merely a trade-illustration of the fact that in ripening fruits we have to do with objects endowed with life. But it raises in the mind the question : in what does ripening of pulpy fruits really consist, and why does it happen ? There may be differences in detail in the ripening process in various fruits, but, speaking generally, the chief changes are these. In the young green fruit as it swells starch usually accumulates, together with a variety of acids and tannins, which make the hard unripe flesh unpleasant to the taste. But as ripening approaches, the starch is rapidly converted into sugar by the action of the ferment diastase ; there is an increase also in those

pectic substances which form the basis of all fruit jellies ; and this goes along with a general softening of the cell-walls. Other ferments act upon the proteins present, breaking them up ; while there is a formation of fruit-ethers and other aromatic substances to which the particular scent and flavour of the fruit are due. The acid and astringent taste of the unripe fruit disappears with mellowing, and instead a sweet taste develops. This is due to sugar formed by the conversion of the stored starch, and it may be also of the acids themselves in part, while part of the acids present is oxidised and passes off as carbon-dioxide. Besides these changes, the formation of pectic substances, already mentioned, softens the whole mass. The combined result is what we call mellowing. Meanwhile a change of colour also supervenes : the green chloroplasts become converted into or substituted by red or yellow chromoplasts ; these, together with other colouring matters in solution in the cell-sap, give the attractive tints. Lastly, those scents are acquired which give further individual character to the different fruits. All these changes are essentially due to processes of degradation. They are all steps in the return of material originally gained by the photo-synthetic process carried on by green chlorophyll in presence of light. Light is not necessary here for the ripening, which is itself a reversal of that constructive change. The very fact that respiration— that is, the taking in of oxygen and giving out of carbon-dioxide— is active during the process is sufficient evidence of the sacrifice of material which the fruit makes as it ripens. Combustion of part of its substance gives the impulse to those changes the results of which we value in the ripe fruit.
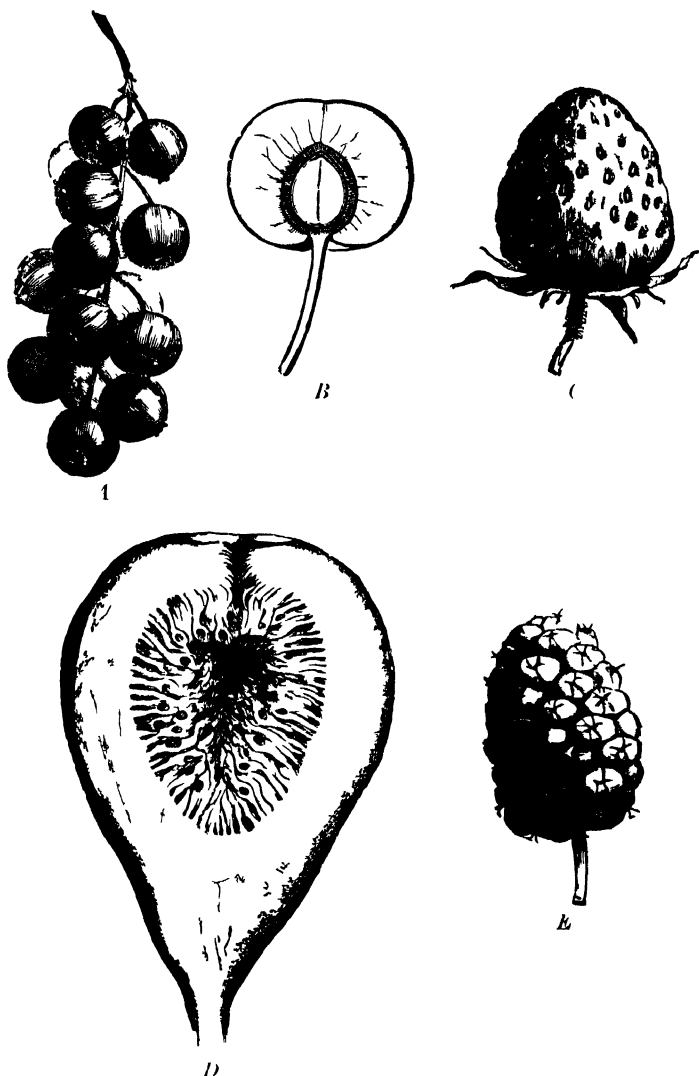
But if there is thus a sacrifice of material gained
tediously by photo-synthesis, why does this happen ?
Would it not be better for the plant to conserve it all,
as dry fruits do ; or best of all to store it in the seeds
for the use of their embryos on germination ?   It is
in the ultimate interest of the young plants that the
sacrifice should be made.   The loss is biologically
justified by interaction with living mobile animals,
especially birds.   Attracted by the colour, scent, and
flavour of the juicy fruits, they eat the pulp and the
seeds together, and the latter, passing through the
alimentary tract alive, are deposited at a distance.
The point gained is the distribution of the progeny,
thereby securing to each individual seedling an im-
proved chance in the competition in a grossly over-
stocked world.   This is the biological rationale of
all pulpy fruits.   The price paid by a sacrifice of
substance in the pulp eaten is not too high.

It is well to give a specific instance of the practical
success of this method of distributing the seed of
plants, which being fixed in the soil cannot effect it
for themselves.   In the neighbourhood of Cambridge
the Willows are habitually " pollarded," that is, they
are docked to a level of about eight feet from the
ground, whence strong branches shoot forth, which
are again cut at regular intervals.   As time goes on the
stumps widen, and their tops collect humous soil on
which quite a flora of Flowering Plants may grow.
But they are perched some eight feet above the ground :
how do their seeds get there ?   A census was made
some years ago of these plants.   Out of 4000 records
44·62 per cent. were plants with fleshy fruits ; 25·18
per cent. had winged or feathered fruits or seeds ;
16·47 per cent. had burred fruits ; and 10·75 per

cent. had seeds so light and small that they would
be easily borne by wind to their strange quarters.
The burred fruits are accounted for by their
clinging to the feathers of birds; but the largest

FIG 68 — FRUITS DEVELOPED IN RELATION TO TRANSFER OF SEEDS
BY THE WIND AND BY ANIMALS   A = seed of Cotton shed from
the capsule being a tuft of superficial hairs B dry fruit of
Valerian with the persistent calyx developed as a feathery parachute
(After Figuier)

proportion consisted of plants with fleshy fruits, the
seeds of which had clearly been borne internally by
birds and deposited during roosting, even in so un-
propitious a habitat as these " hanging gardens "
actually are.
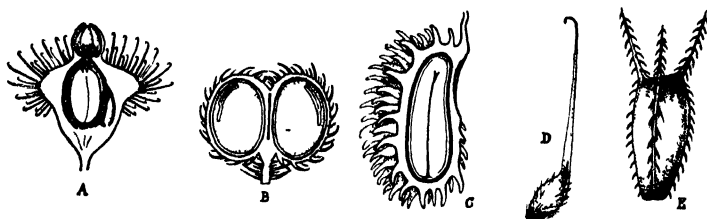
FIG 69 —A GROUP OF DRY FRUITS, with hooked outgrowths,
effective in transfer by animals   A Agrimonia (Ic Miout) , B
Galium (Le Miout)   C   Cynoglossum , D   Geum , L —Bidens.

In the breeding and cultivation of our dessert fruits
Nature has been improved upon, and sometimes even
cheated. Already in the discussion on garden vege-
tables it has been shown how by culture, hybridisation,

and selection certain breeds of plants may be stretched
to the limit of fluctuating variation, and kept there ;
and the result is seen in the high-class products of the
vegetable plot.   It is the same with fruits.   A parallel
in this respect might justly be drawn between the
succulent Carrot or Beet, so different from the stringy
roots of the wild forms we know, and the luscious
dessert Pear so different from the small wild Pear with
its woody core.   The grits or nests of hard and woody
cells scattered in the soft pulp are believed to repre-
sent that core resolved into small isolated granules,
as a consequence of selection under cultivation.   More
remarkable still is the production of stoneless Plums.
Inside such a Plum is the seed, looking like an Almond,
but without any stony covering, so that the whole
fruit may be bitten through.   The seed is surrounded
by a pale jelly with only some few remnants of the
stony tissue.   Passing from such improvements as
these, it might seem little short of a biological fraud
for any race of plants to be induced to continue ripen-
ing succulent fruits without any seeds at all within.
But of this there are many instances among cultivated
races.   The Pine-apple, the Banana, and the pip-less
Oranges are familiar examples.   Sultana Raisins are
seedless.   We are promised also pip-less Apples and
Pears of high quality, though hitherto those produced
have not been able to compete on the market with
their normal relatives.   It may remain a mystery how
it is (so to speak) worth while for a plant ever to produce
such fruits, which are without the essential reason for
the fruit's existence.   The question is similar to that of
doubled flowers that have neither functional stamens
nor carpels.   In either case the plants have been
encouraged by cultivation to continue an expenditure

of material that is biologically indefensible. The first initiation in this wasteful course may have been through a useless mutation, which would in Nature have been eliminated at once by natural selection ; or, if it produced any functional pollen or ovules at all, have been swamped by crossing with preponderating normal specimens. But the horticulturist has preserved it for his own ends, though it is a biological absurdity.

We naturally connect the idea of mellowing with that of decay, for the latter so often follows closely on the former, as any dish of Pears may show. But there is no necessary connection between the two. Any jar or tin of preserved soft fruits suggests that, if proper precautions are taken, and if the receptacle itself were ideal, the ripe fruit could be preserved for a long time. Indeed a definite limit or period can hardly be specified. There is nothing in the tissues themselves that causes decay beyond the fact that a soft watery medium, with plenty of soluble carbohydrates and other nutritive substances contained in it, presents the best of soil for fungal and bacterial growth ; and that is what a succulent fruit actually is. The consequences of the action of intrusive organisms on the tissue of the fruit are what we include under the general word decay. Some fruits are more vulnerable than others. The Strawberry or Raspberry, especially when their thin outer skin has been bruised by transit, are peculiarly ready victims, and delayed consignments are soon spoiled by growths of Fungi, such as the black-headed *Rhizopus*, or by the ashy growths of *Botrytis*. The Tomato, equally soft within, is protected by a tough impervious skin, and is thus better fitted for keeping the invaders at arm's

length, provided the skin remain intact.   Discolora-
tion of the skin or of the internal tissue usually serves
as a sign of fungal attack ; but this is not always a
safe guide.   An exception is seen in the Banana, in
which the normal transition from yellow to deep brown
or black is not an index of decay.   It is due to the
action of an oxydase upon some aromatic substance
liberated in the superficial tissue ; it thus follows on
changes from within, and may be held rather as an
indication of the full ripeness of the fruit.
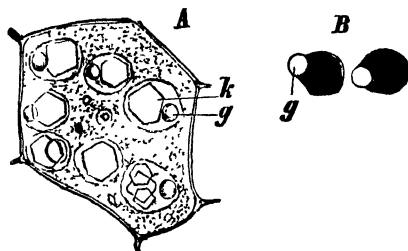
FIG. 70 —This illustration of the way in which protein and oil are
stored in a dry seed is taken from the Castor Oil Plant ; but it will
serve as an example of what is seen in other oily seeds. A - a
single cell containing several oval aleurone grains composed of
protein, and embedded in an oily matrix of protoplasm. B - isolated
aleurone grains ; k crystals of albumen ; g globoid. (After
Strasburger)

Returning now to the Almonds, Walnuts, and Fil-
berts, analysis shows that while the proportion of
water in these torpid bodies is very low indeed as
compared with active tissues, there is a large pro-
portion of nitrogenous material in the large germ, and
a still larger proportion of the whole weight consists
of oil, in fact more than half of the whole weight.
Oil is the most condensed form in which combined
carbon can be stored, and the biological end is the
largest supply for the young germ laid by in the most
compact form.   It is their high nutritive content that
makes seeds the staple food for animals and for
Man.   The larger the store the greater the prize.

That stores so vulnerable should be protected has probably been the condition of survival of the larger germs in face of the predatory attacks of animals, and incidentally of Fungi as well, This is the biological meaning of the hard nut-shell. But sometimes the protection may be overdone. However great the disruptive powers of a growing and swelling plant-tissue, horticulturists know well the difficulty that the shell sometimes opposes to it, and how greatly the certainty of germination is promoted in extreme cases by filing or cracking it, so as to help the seedling to emerge. The seeds of Sweet Peas and Lupins are habitually chipped for this reason.

The test of the vitality of the dormant germ within is not simply to examine it but to submit it to conditions favourable for germination, as is the regular practice at seed-testing stations. It is in this way that the possible duration of the dormant period may be experimentally defined. Some seeds will germinate directly they are mature ; the Grasses do this, and in a wet warm season Wheat will sprout in the stook before it can be harvested. But, as a rule, a period of rest follows ripening, and a resting period may even be obligatory. The Sycamore will not respond till the spring, and then all the seeds sprout simultaneously. Ash seeds are said to lie dormant for two years, while individual seeds of Laburnum and Mignonette are variable. Naturally we shall ask what is the length of time during which the vitality of seeds can be retained. Experiments show that while the seeds of Mallows and Pea-flowers are long-lived, those of *Compositae, Cruciferae,* and Grasses soon lose their germinating powers. An extreme example of longevity has been seen in the seeds of the Sacred Lotus, which germinated after

having been kept dry for 160 years.   It is, however,
a long step from this to the supposed germination of
" mummy-wheat."   A. de Candolle, examining the
evidence up to 1882, concluded that no grain taken
from an ancient Egyptian sarcophagus and sown by
horticulturists has ever been known to germinate ; nor
is there any trustworthy evidence to the present day.
We know better now than before how far Egyptian
burials have been tampered with by illicit hands, and
can judge how easily spurious materials may be substi-
tuted, on which experiments would be misleading.
Notably the grains of Grasses are short-lived, while in
those actually taken from mummies the germ is found
to have perished.   But though we see that the pre-
servation of vitality has its term, from our Nuts we
learn to contemplate a state of suspended animation
common for seeds ; it is conspicuous in the seeds sold
by seedsmen for germination.   The period during
which vitality is retained when life is thus toned down
may sometimes be long, but not indefinite.   Any dish
of Brazil Nuts may make us unhappily aware of this.
From such considerations we may conclude that the
legend of the " mummy-wheat " seems as fanciful as
is the story of Rider Haggard's *She*.

CHAPTER XV

CEREAL GRAINS

IF we inquire which of all the diverse families of plants
is the most useful to Man, three stand out as probable
claimants for the premier place. People who live in
the tropics, and are naturally impressed by such plants
as the Coco-nut, the Date-palm, or the Oil-palm, may
think first of the Palm family ; but these plants in-
habit almost exclusively the tropical belt, and the
successful competitor must surely be cosmopolitan.
Another family, which does meet this requirement
fully, is the *Leguminosae*, to which the Peas and Beans
belong. It includes plants yielding many timbers,
dyes, and drugs, as well as important foods and forage
plants. Few if any families can compete with them
in the variety of their supplies, or in wideness of their
distribution on the earth's surface. But even these
must yield before the Grasses. It is true the pro-
ducts of this family are not greatly varied, for it does
not supply dyes or drugs, nor yet timbers, excepting
the Bamboo, that versatile aid at need to Man in the
tropics. But the Grasses are the source of those
staple foods which are based upon the cereal grains,
while indirectly their herbage also comes to us trans-
muted into beef and mutton.

The success of this wonderful family rests very largely upon the way in which individual plants extend over the soil by horizontal shoots or stolons, which root at the nodes. By this means a single plant may spread indefinitely in all directions, while from the tip of any of the shoots a flowering stem or ear may arise. Another factor of their success is that they are pollinated by means of the wind, or sometimes they are even self-pollinated, as is the Wheat, without the flowers expanding at all. Further, though each flower produces only a single grain, the flowers themselves are unusually numerous, while each grain is so well supplied with stored food that on germination the new individual starts life under advantageous conditions. Few grains fail in ability to produce a prosperous seedling. Given also such a reasonable degree of adaptability as we see in many of them to climate and circumstance, we need not be surprised to find the Grasses cosmopolitan in their spread, and preponderant among land-plants throughout the world.

The grain of the Grasses is of the nature of a nut. Each grain is the product of an individual flower ; these flowers are as a rule associated together in closely packed spikelets, and these again into dense " ears," as in the Wheat or Barley ; or the spikelets may be borne in lax trusses, as in the Oat, Rice, or Millet (Fig. 71). The flowers of Grasses, being wind-pollinated or self-pollinated, are never showy, and a very general and characteristic feature is that protective leaves of simple form surround the grass-flowers ; in particular two of these, known as " paleae," enclose each individual flower, while others, called " glumes," afford additional protection outside. These are all green while young, but they become dry and

membranous as the grain ripens, and constitute what
is known as the "chaff" that is winnowed away
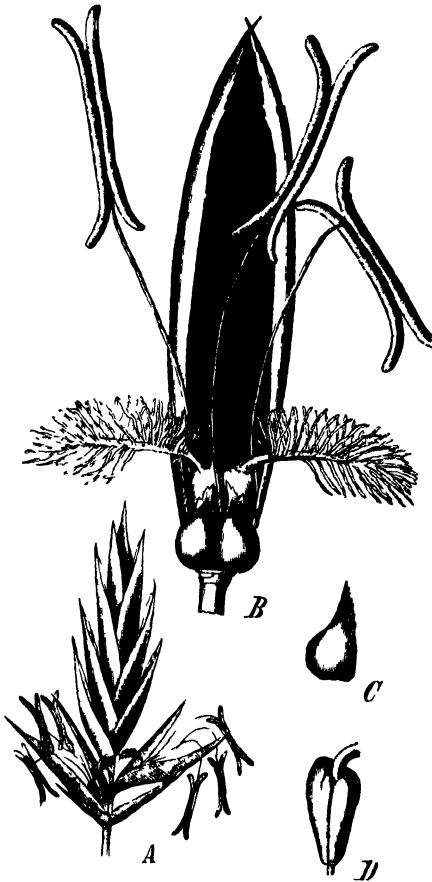
FIG. 71 —.1 a spikelet of a Grass (*Festuca*), showing at the base
two open flowers, each seated between a pair of "paleae," and below
them again the sterile "glumes"; above are alternate pairs of
"paleae," with flowers not yet mature. (× 3) *B* =a single flower
in front view; below are the two turgid lodicules, centrally the ovary
or future grain, with two leathery stigmas; surrounding it, the three
stamens with long thin filaments, and large anthers; at the back the
inner palea. (> 12.) *C* =a single lodicule. (12) *D* = the ovary
seen from the side with the stalk of one of the removed stigmas.
(12) (After Strasburger.)

when the grain is detached by thrashing. Some
grains then come clean away, being easily cleared
of their chaffy protections, as in the Wheat, Rye, and

Maize. In others the coverings adhere more or less closely to the grain, as in the Spelt-Wheat, Barley,
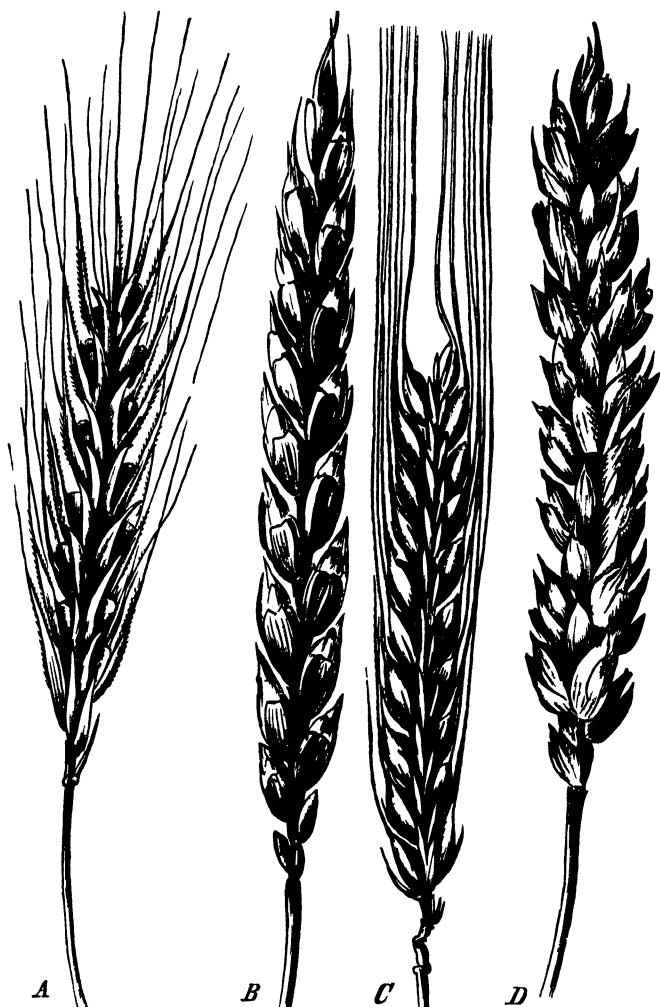
FIG 72   EARS OF VARIOUS CEREALS each composed of a central rachis or stalk bearing rows of spikelets   alternately right and left   A   Rye (*Secale cereale*)   B   Spelt Wheat (*Triticum spelta*)   C   Two ranked Barley (*Hordeum vulgare distichum*)   D = Wheat (*Triticum vulgare*)   (After Strasburger)

and Oat ; in some, such as the Rice, special milling is then necessary for cleaning the grain (Fig. 72).

The structure of the grain of the Grasses is essentially the same in them all, though the details and proportions may vary, as well as the chemical composition. Accordingly a description of what is seen on examination of a grain of Wheat will serve as a general example. How many of those who eat wheaten bread at every meal have ever examined a Wheat-grain, or have any clear idea of its preparation before it is presented to them as their familiar staff of life ? The grain is a fruit in the sense that it consists of the whole pistil, or gynaecium of the flower, and consequently we expect in its construction to find an external fruit-coat representing the wall of the ovary, and an inner seed-coat derived from the integument of the ovule. These are, however, so closely united in the ripe grain that they appear as a single shell, and breaking as a brittle shell would in the process of milling, the sharp, angular fragments present themselves as " bran." This outer double wall covers and protects the essential parts within. By far the greater bulk of the grain is taken up by the storage-tissue of the endosperm, mealy in texture in the Wheat ; hence it breaks up readily to powder in the milling process, and yields the starchy " flour." Towards the base of the grain and in a lateral position lies the " germ," a small, flattened, oval body that may even be recognised from the outside of the dry grain as a slightly wrinkled and depressed area (Fig. 73). The germ is the young plant ; it is waxy in consistency, and in the process of roller-milling it is flattened out into a little yellowish scale that can be separated from the rest in the siftings which follow the crushing or grinding of the grain ; it may then be used in the making of so-called " germ-breads." These several parts are

present in very different proportions. About 85 per cent. of each grain consists of endosperm : the bran amounts to about 13·5 per cent., while the germ
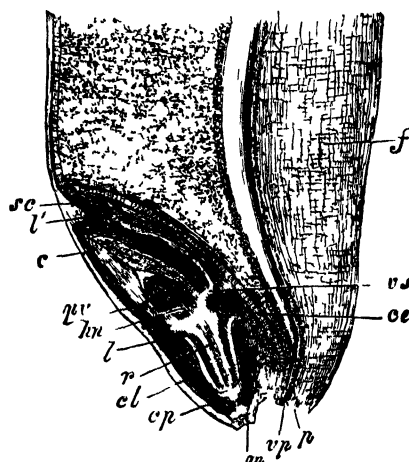
FIG 73 —PART OF A MEDIAN LONGITUDINAL SECTION OF A GRAIN OF WHEAT, showing the embryo and the suctorial scutellum (sc) vs vascular bundle of scutellum   ce —its columnar epithelium l   ligule c —sheathing part of the cotyledon pv —vegetative cone of stem , hp —hypocotyl , l epiblast   r radicle   cl root sheath m —micropyle , p tuniculus , vp vascular bundle of tuniculus f lateral wall of groove of the grain ep pericarp   (×14) (After Strasburger)

accounts for only 1·5 per cent. of the weight of the whole grain.   The analyses of these several parts are given in the subjoined table :

Wheat.	Water	Nitro genous sub stances	Fats	Digest ible Carbo hy drates	Cellu lose and Lignin	Ash
Whole Grain, 100 per cent	14·5	11·0	1 2	69·0	2·6	1 7
Bran, 13·5 per cent	12·5	16·4	3·5	43·6	18·0	6·0
Endosperm, 85 per cent	13 0	10 5	0·8	74·3	0 7	0 7
Germ, 1·5 per cent	12·5	35 7	13·1	31·2	1 8	5 7

From this it appears that the whole grain consists very largely of carbohydrate, chiefly in the form of starch ; that the nitrogenous substances rank second in the organic constitution of the grain, though in less proportion than is desirable in an ideal food for Man ; while the indigestible cellulose and lignin, the fats and ash, are only present in small proportion. Comparing the analysis of the whole grain with that of the bran, it is seen that the latter contains a much higher proportion of nitrogenous substance, of fats, indigestible carbohydrates, and ash, while the starch is markedly less in proportion than in the whole grain. The germ, on the other hand, is remarkably rich in nitrogenous substance, fats, and ash, but it has a lower percentage both of digestible and indigestible carbohydrates than the whole grain. The endosperm shows, however, a slightly lower proportion of nitrogenous substance, a higher percentage of digestible carbohydrate, and very low of indigestible carbohydrate, fat, and ash. This information will illuminate the study of the products of milling.

The purpose of milling was in the first instance simply to grind the grain into small parts, and the bread of primitive Man was doubtless " wholemeal " bread, which many hold to be the best of all wheaten bread. But even in the old stone-grinding the products were usually graded roughly as bran, pollard, sharps, middlings, and fine flour. Sometimes the coarser products were re-ground, and the fine flour again extracted from them ; but mostly they were regarded as " offals," and were fed to stock in various forms. Under stone-grinding the germ was no doubt torn to shreds, and remained in the flour, much to its advantage from a nutritive point of view. More

recently in the process of roller-milling the grain is comminuted more accurately by successive stages, being passed through rollers with successively finer ridges. The products of these successive " breaks " are sifted, partly by screens, partly by air-blasts so arranged that their various grading can be very perfectly carried out. The end-product of greatest importance is the flour. The finer this flour is graded the less percentage of it will be yielded from the milled grain, but the whiter will be the bread. In pre-war days about 70 per cent. of the whole grain was yielded as the finest flour. But already before the war a reaction on grounds of nutrition had led to a preference for '' standard flour,'' which was defined as " 80 per cent. of the grain, with all the germ and semolina." It gave a well-flavoured nutritious bread, but not of extreme whiteness. After the outbreak of war stricter economy made it necessary to extract even a higher percentage of flour from the grain. The Scientific Commission of the Allied Countries recommended a uniform milling extraction of 85 per cent. for Wheat. This necessarily gives a lower grade, but no objection is possible on grounds of nutrition. In the absence of restrictions under the conditions of peace, there is naturally a reversion towards pre-war practice ; but this will inevitably bring with it the risk of impaired nutritive quality.

It will be seen that the flour extracted in milling corresponds approximately in amount to the whole of the endosperm. Within narrow limits this is actually the fact, but with one important exception. . The analysis of bran shows a high percentage of nitrogenous substances and of fats. The explanation of this is that a layer of cells just within the protective

coat, in fact the superficial layer of the endosperm,
contains those substances in special quantity. This
so-called " aleurone layer " adheres to the fragments
of the bran, and comes away with them. The
horses that get a bran-mash are the gainers, but
those who eat bread made from the white flour are the
poorer by the removal of a proportion of those very
substances in which the fine flour is deficient. The
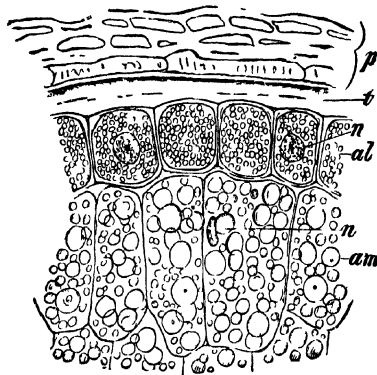
FIG. 74 PART OF A TRANSVERSE SECTION OF A GRAIN OF WHEAT
with the outer surface uppermost   p pericarp   t testa   and
these together form the woody covering which is scaled off as "bran"
Within this is the Endosperm, of which the outermost layer (al), is
the so called aleurone layer   the thin walled cells within contain
starch grains (am), and nucleus (n)   (×240) (After Strasburger)

extraction of the germ in the sifting processes of the
roller-mill acts again in the same direction. The germ
of Wheat contains no starch, but soluble sugar, protein,
fats, and ash are present in high proportion. The
removal of these, even though they together account
only for 1·5 per cent. of the whole grain, impoverishes
the flour that remains in respect of some of its most
important constituents. The presence of fragments
of the germ is said to give an undesirable colour to
the flour, and to deteriorate its keeping qualities.
That may be so, but the finest grade of white flour has

lost the specially nutritious germ ; a disadvantage remedied in germ-breads by adding various proportions of the extracted germ in the preparation of the dough. The whitest bread is not the most satisfactory as a staple food, though this may be immaterial where a generous mixed diet is used. Least of all should the " jelly-piece " be tolerated for children, especially if it be a slice of white bread, that is made speciously attractive by jam ; for it is nothing short of a physiological fraud on the young. The jam, or " jelly," merely adds more carbohydrate to a bread that already has it in too high a proportion. Butter, dripping, or even margarine in place of, or in addition to the jam would be infinitely better for the child.

It must not be thought that Wheat is uniform in composition. Comparison of samples of different strains, from different countries, and grown under different conditions, will show considerable variations of analysis. Part of the science of the bread factory consists in blending the different samples so as to produce a loaf of uniform quality day by day. One of the most distinct types of Wheat is the so-called " Glass-Wheat " of Southern Europe, which is specially rich in protein. This produces a tenacious dough, particularly suitable for making macaroni and vermicelli. Another familiar product of Wheat is " semolina," which is sifted out from the crushed grains of the roller-mill. It consists of coherent masses of endosperm-tissue, which are graded according to their size and sold for puddings.

Notwithstanding these familiar uses to which the Wheat-grain is put, it probably stands second only as a staple food for mankind. A larger proportion of the human race depends upon Rice for subsistence.

Doubtless the Wheat-eaters are catching up the Rice-eaters in point of numbers, but it will probably be long before a balance is reached. The natural Rice-grain has a rough husk, which represents about 6 per cent. of the whole weight. This husk is indigestible, and has to be cleaned off before use. The Rice imported into this country and sold in the shops is " cleaned Rice," with the husk removed. It is also polished in the mills ; in that process it loses the superficial layer of the endosperm, which is the physiologically important aleurone-layer. This lowers its value as a staple food, for the proteins are already deficient in the whole grain. But in a Rice pudding the loss in proteins and the deficiency in fats is made up by the added milk and butter, while in curries fats and proteins are added to the Rice in sufficient quantity to constitute the whole a good comprehensive diet. The composition of the uncleaned Rice is seen in the subjoined table, in comparison with that of other grains.

TABLE OF ANALYSES OF CEREAL GRAINS

Name.	Water.	Nitrogenous substances.	Fats.	Digestible Carbohydrates.	Cellulose and Lignin.	Ash.
Wheat - - -	13·37	12·04	1·91	69·07	1·90	1·71
Rye - - -	13·37	10·81	1·77	70·21	1·78	2·06
Barley - - -	14·05	9·66	1·93	66·99	4·95	2·42
Oats, average of all lands - - -	12·11	10·66	4·99	58·37	10·58	3·29
Oats, England and Scotland - -	12·11	13·05	6·15	53·16	11·89	3·64
Maize - - -	13·35	10·17	4·78	68·63	1·67	1·40
Rice (not cleaned) -	11·99	6·48	1·63	70·07	6·48	3·33

Of the cereals thus analysed, the most important for Northern lands is the Oat, by reason of the fact that

the plant is hardy enough to ripen its grain under the
rigours and vicissitudes of a severe climate. If a
comparison of its analysis be made with those of other
cereals it is at once apparent how high it stands as a
staple food. Though a rough grain, as shown by the
high percentage of cellulose and lignin, it contains an
exceptionally high percentage of proteins, fats, and
ash, and consequently a less undue proportion of
starch. The addition of milk and salt to porridge
accordingly makes an ideal food. Those who have
read Hugh Miller's book, *My Schools and Schoolmasters*,
may remember how, as a working stonemason, he
would go to a remote job with a bag of oatmeal over
his shoulder, and live upon it, with or without milk,
while doing hard bodily work. Unfortunately this
good example is losing its effect with the modern
Scot, who, especially in towns, is less dependent than
heretofore on oatmeal, and substitutes for it white
wheaten bread. He is in danger not of selling his
birthright for a mess of pottage, but of giving away
both his birthright of good health and his pottage to
save the time and trouble of cooking it, or to indulge
a taste for a more varied diet. It may be recalled
how Dr. Johnson defined the Oat as " a grain which
in England is generally given to horses, but in Scot-
land supports the people " ; and Lord Elibank's
caustic rejoinder to this epigram, " Yes, and where
else will you find such horses and such men ? " One
reason for their high quality comes out clearly from
the above table, showing the Oat among other grains
analysed. Further, it will be remarked upon the table
that the composition of Oats from all lands is already
superior to that of any other cereal grains in percentage
of proteins, fats, and ash. But the average analysis

of Oats from England and Scotland is again superior to that of the Oats of all lands on all three counts. It may be a question what is the reason for such superiority of British Oats. The explanation may very likely be climatic. It is only one example among many of the exceptional advantages of these islands, which have made them a centre of distribution of high-grade products, not of cereal grains only, but of bloodstock of various sorts, used for maintaining the quality of cultivated races in other lands.

CHAPTER XVI

VEGETABLE FOODS

MAN is an omnivorous animal by organisation and by general custom. Occasionally he may by the force of circumstances be carnivorous, as are the Esquimaux ; on the other hand, he may at times be vegetarian by compulsion or, forswearing animal food altogether, he may be so by predilection. But a combined diet of animal and vegetable food is certainly the most natural and effective for him, though it is possible for him to subsist well upon vegetable foods alone. There are various animals which can digest wood, and even cork, such as boring beetles and white ants ; but all the harder plant-tissues are beyond the physiological reach of Man. Woody walls and even those consisting of cellulose are indigestible for him, and he depends upon extracting from his vegetable foods the protein contents of the cells, together with the digestible carbohydrates and oils associated with them. Naturally, this being so, he will select his food from those parts which are succulent and the cell-walls thin, and will avoid those in which the tissues are fibrous and woody. Accordingly, young shoots, green leaves, storage-tubers and roots, or fruits and seeds, are the sources upon which Man draws for his supplies.

The vegetable foods in common use may be classed thus :—(i) those taken in the active vegetative state, as green garden vegetables ; (ii) legumes and pulses ; (iii) fresh fruits ; (iv) dry fruits ; and (v) cereal grains. In all of these the important constituents, or "proximate principles," are (a) *proteins*, involving carbon, hydrogen, oxygen, and nitrogen in their composition ; (b) *carbohydrates*, which involve carbon, hydrogen, and oxygen, but not nitrogen ; and (c) *fats*, involving the same constituents as the latter. *Water* is present in varying quantity, being naturally smallest in dry fruits and grains, while in fresh vegetables and fruits it may amount to 80 per cent., or even more than 90 per cent. of the whole weight. *Salts* are also present, especially sulphates and phosphates, figuring in analyses as ash ; they provide essential elements in the complete food of Man. The proportions of these several constituents may vary in very high degree, and consequently the nourishing quality of the particular article as food will also vary. The amount of these constituents of food required daily for the diet of a man doing moderate work may be stated as : protein 100 grammes. fat 90, carbohydrate 400-500 grammes. This statement may serve as a general guide in estimating the comparative values of the vegetable food-stuffs. In ordinary life a diet is so mixed that a deficiency of some constituent in one article of food is compensated by a surplus of it in another. For instance, butter added to bread makes up for the deficiency of fats in flour, and meat eaten with potatoes supplies their deficiency in proteins and fats, and balances their surplus of carbohydrates. But, though vegetable food-stuffs are habitually used only as part of a mixed diet,

it is well to know the constitution of the chief of
them.

TABLE OF ANALYSES OF ROOTS AND SHOOTS

Name.	Water.	Nitro-genous sub-stances.	Fats.	Digest-ible Carbo-hy-drates.	Cellu-lose and Lignin.	Ash.
Potato - -	74·98	2·08	0·15	21·01	0·69	1·09
Beetroot - -	82·25	1·27	0·12	14·40	1·14	0·82
Parsnip - -	79·31	1·32		16·36	1·73	1·28
Onion -	85·99	1·68	0·10	10·82	0·71	0·70
Carrot - -	86·79	1·23	0·30	9·17	1·49	1·02
Turnip - -	87·80	1·54	0·21	8·22	1·32	0·91
Cauliflower -	90·89	2·48	0·34	4·55	0·91	0·83
Winter Kale -	80·03	3·99	0·90	11·63	1·88	1·57
Celery - -	84·09	1·48	0·39	11·80	1·40	0·84
Spinach - -	88·47	3·49	0·58	4·44	0·93	2·09
Lettuce - -	94·33	1·41	0·31	2·19	0·73	1·03

The high water-content of all of these makes the
proportions of the other substances appear small,
otherwise the figures speak for themselves. But the
high proportion of starch in the Potato is notable,
and the high sugar-content in the Beetroot and Par-
snip, as also the very low percentage of fats in them
all, while in none of them is the nitrogenous content
large. These features suggest for garden vegetables
that they are to be regarded as accessories rather than
as staple foods. They explain why they are habitu-
ally eaten with meat, which levels up their deficiency
in fats and proteins.

A word must be added on the Lettuce, which may
be taken as an example of salads. It may surprise
those who think of a fresh Lettuce as a firm, crisp
object, to learn that only some 5 or 6 per cent. of its
weight is organic material, and that all the rest is

water. The mechanical aspect of this astonishing fact will be taken up later. Meanwhile we shall realise that eating salad is from the point of view of direct nutrition little different from drinking so much water. We shall, however, see later that fresh vegetables have a very special importance of their own for healthy nutrition.

TABLE OF ANALYSES OF LEGUMES AND PULSES

Name.	Water.	Nitro-genous sub-stances.	Fats.	Digest-ible Carbo-hy-drates.	Cellu-lose and Lignin.	Ash.
Bean - -	13·49	25·31	1·68	18·33	8·06	3·13
Parched Peas -	13·92	23·15	1·89	52·68	5·68	2·68
Lentils - -	12·33	25·94	1·93	52·84	3·92	3·04
Soja Beans -	12·71	38·18	14·03	31·97	4·40	4·71
Arachis - -	7·71	31·12	46·56	9·39	2·16	3·06
Green Peas -	78·44	6·35	0·53	12·00	1·87	0·81
French Beans -	88·75	2·72	0·14	6·60	1·18	0·61

The Legumes are notable for the high protein-content of their seeds. The low water-content of their parched seeds or Pulses averaging about 13 per cent., the other constituents appear to stand high as compared with the previous table, and with the analysis of Green Peas and French Beans, which are naturally taken in the fresh state. The analysis shows them to be highly nutritious. But the fully matured seeds have thick cell-walls, which render them difficult of digestion, hence their frequent use in thoroughly cooked Pea or Lentil soup. They mostly show a deficiency of fats, which is the natural justification of bacon and Beans. This charge of deficiency cannot, however, be brought against the Soja Bean, largely grown in Manchuria, and now imported in quantity.

Unfortunately this prolific plant has not yet made its
way as a remunerative crop under the conditions of
the British climate.   The seeds of Arachis—the Mon-
key-nut—contain a very large proportion of fats ; but
on account of its flavour it is not a favourite food
with Man.

TABLE OF ANALYSES OF FRESH FRUITS

Name.	Water.	Nitro-genous sub-stances.	Free acids	Sugar.	Other digest-ible Carbo-hy-drates.	Cellu-lose and Lignin.	Ash.
Apples - -	84·79	0·36	0·82	7·22	5·81	1·51	0·49
Pears - -	83·03	0·36	0·20	8·26	3·54	4·30	0·31
Plums - -	84·86	0·40	1·50	3·56	4·68	4·43	0·66
Peaches -	80·03	0·65	0·92	4·48	7·17	6·06	0·69
Apricots -	81·22	0·49	1·16	4·69	6·35	5·27	0·82
Cherries -	79·82	0·67	0·91	10·24	1·76	6·07	0·73
Grapes - -	78·17	0·59	0·79	14·36	1·96	3·60	0·53
Strawberries -	87·66	0·54	0·93	6·28	1·46	2·32	0·81
Raspberries -	85·74	0·40	1·42	3·86	0·66	7·44	0·48
Blackberries -	86·41	0·51	1·19	4·44	1·76	5·21	0·48
Gooseberries -	85·74	0·47	1·42	7·03	1·40	3·52	0·42
Currants -	84·77	0·51	2·15	6·38	0·90	4·57	0·72

The most striking feature in the analysis of fresh
fruits is their high water-content.   It is not quite so
high as that of the fresh Lettuce, and the reason for
this is chiefly the presence of sugar, which naturally
makes them attractive.   But upon it also depends
their value in the production of wines, in which the
Grape, with its 14 per cent. of grape-sugar, takes the
precedence.   Apples and Pears, the sources respec-
tively of cyder and perry, have also a high sugar-
content ; but Currants and Gooseberries, which have
been used in making " British wines," though follow-
ing closely in this respect, lose their value as sources

of wine owing to their large proportion of free acids. All these points will be gathered from the above table, which also conveys the general conclusion that fresh fruits cannot be regarded as ordinary staples of diet.

It is otherwise, however, with the dry fruits, as shown by the subjoined table :—

ANALYSES OF DRIED FRUITS

Name.	Water.	Nitro-genous sub-stances.	Fats.	Digest-ible Carbo-hy-drates.	Cellu-lose and Lignin.	Ash.
Almond -	6·02	23·49	53·02	7·84	6·51	3·12
Hazel Nut -	7·11	17·41	62·60	7·22	3·17	2·49
Walnut -	7·18	15·77	57·43	13·03	4·59	2·00
Raisins -	32·02	2·42	0·59	62·04	1·72	1·21
Dried Figs -	31·20	4·01		49·79		2·86

The most important of all dried fruits are the grains of Grasses, which are here passed over, as they have been already discussed at length in the previous chapter. Apart from these the Almond, Raisin, Date and Fig have held a peculiar place in the economic life of the Middle East. The Raisin reveals what might have been expected if the water in fresh Grapes were reduced by evaporation, viz. a large content of grape-sugar. Their deficiency as a food is in fats. This is in strong contrast to the Nuts, in which fats figure largely, together with a heavy nitrogenous content, but with little digestible carbohydrate. What, then, can be more natural than to eat them together ? Almonds and Raisins form, indeed, an almost ideal food for the traveller. Not only are they physiologically complementary, but they are also compact and clean. Many a happy day has been spent upon the

hills with Almonds and Raisins, and perhaps a few
Dates in the pocket, and a glorious sense of
physiological independence stimulating the mind and
the muscles.

Such analyses as those contained in the above tables
give, it is true, useful information on the relative
values of the food-stuffs supplied by plants, but they
do not exhaust the subject : for the effect of vege-
table foods is not directly nutritional alone.   They
contain certain " factors " of well-being for animals
and for Man, the prolonged absence of which from
the diet may lead to states described as " deficiency
diseases." These " accessory food factors " have been
designated vitamins, and two of them have been
recognised as being related severally to well-known
diseased conditions, while a third is definitely asso-
ciated with growth.   The real nature of the " factors "
themselves has not been demonstrated as yet, nor
have they hitherto been extracted as pure substances.
But it has been shown that they are so far different
one from another that the three types are not physio-
logically interchangeable.   Each is distinct in its effect,
and probably also in its nature.   They have been
styled as A-vitamin, which is related to and essential
for growth ; B-vitamin, the absence of which is related
to the disease called beri-beri ;   and C-vitamin, the
absence of which is related to scurvy.   The first is
soluble in fat, and exists in green leaves, in cod-liver
oil, butter, and in yolks of eggs ; the second is soluble
in water, and exists in the germs of cereals and other
seeds, in many fruits and vegetables, and in yeast ;
the third is also soluble in water, and exists in most
juicy fruits and vegetables, and especially in lemon-
juice.   The addition of such food-stuffs to an otherwise

defective diet is known to counteract the consequent diseases respectively of beri-beri and scurvy. Since certain animal products have been quoted as containing A- and B-vitamins, it might be thought that the " factors " in question originate equally in the animal or in the plant-body. But it is not so. They may exist at second-hand in animal tissues, but ultimately they are derived from the plant-food which the animal has devoured. It has been ascertained that green leaves may contain all three " factors," but are richer in A- and C- than in B-factor. In this we shall rightly see an additional feature of importance in the use of green vegetable foods, which by mere analysis appear to provide little in the way of positive nourishment. Their free use may be regarded as an insurance against disease.

The importance attaching to fresh vegetables for the maintenance of health is no new idea. In particular, their relation to scurvy was recognised medically in the seventeenth century. Later on Captain Cook, having adopted the result of experiments by Dr. James Lind, which showed that the use of Oranges and Lemons was most beneficial in checking the disease, took suitable measures in victualling his ships, and carried through his long voyages keeping his crews singularly free from it. But such remedies are not always accessible. Dana, writing in 1840 in *Two Years Before the Mast*, graphically describes the effect of a supply of fresh vegetables towards the end of a long voyage. He tells how their ship, when homeward bound, fell in with an outward-bound brig and secured from her a liberal supply of fresh Onions and Potatoes. How the sailors ate them raw and ravenously, filled their pockets with them, gnawing them

in their watches on deck. The effect on the scurvy-stricken men was remarkable. One who had been lying helpless in his berth was, within ten days, aloft furling a royal. The C-vitamin had done its work.

Already Dr. Lind had found that a convenient method of holding scurvy in check was the use of Cress-seedlings grown on layers of cotton-wool. This, as well as other more recent experiences with germinating pulses, may have suggested to the officials of the Lister Institute the curative measures recommended by them for our scurvy-stricken forces in Mesopotamia during the Great War. Peas, Beans, and Lentils, or, alternatively, Wheat, Barley, or Rye were then used. The seeds, sent out dry, were germinated as required. They were soaked in water twenty-four hours and then kept moist and aerated till they sprouted. The subsequent cooking must be short, not more than twenty minutes ; for prolonged high temperature, or, worse still, heating a second time, destroys the curative effect, and still more so if the temperature be raised to 115 degrees C. or 120 degrees C. Drying is also found to be destructive, hence the comparative uselessness of dried vegetables. The fact is that these accessory "food-factors" are delicate and susceptible bodies, inherent in living plant-tissues. Prolonged cooking, drying, or artificial preservation diminishes or actually destroys their effect.

While we shall thus accord peculiar value to the detection, use, and qualities of these obscure bodies, it is well to realise that the actual substances (if they really exist as such) have not yet been isolated, much less analysed or classed. Their great importance to the well-being of the population, especially in urban centres, has brought them into prominence, and

introduced their names and identities to many who are unused to scientific criticism, or to that suspense of judgment that so often follows necessarily from it. Some may therefore be inclined to regard these " factors " as things more definite and better known than they really are. In many questions discussed by scientific men, and in particular in speaking of these vitamins, we shall do well to remember the ironic injunction so whimsically expressed by Mr. Belloc, that

> " You should never, never doubt
> What nobody is sure about."

Opinion must be held in suspense as to the real nature of the " accessory food-factors " until these elusive bodies have been brought to actual demonstration. But there is no doubt as to the reality of their effect. They are necessary to health, and are most conveniently introduced into a mixed diet in the form of green vegetables or of fresh fruits.

CHAPTER XVII

MECHANICAL CONSTRUCTION OF PLANTS

(*A*) The Turgescent Cell

WHEN the blind man of Bethsaida, with his half-recovered sight, said, " I see men as trees walking," his expression owed its graphic touch to the incompatibility of the statement with common experience. Not only are trees fixed and animals as a rule mobile, but the body-mechanism of the two is essentially different. The dynamic muscular contractions of the animal body, rendered effective in producing movement by their action on the bony levers, have no counterpart in the plant-body. Such movements as are seen in young parts of plants arise from a totally different mechanism, and are lost in the stiffened adult. Trees, shrubs, and herbs lack the power of moving their mature limbs. Still, they present mechanical problems of fascinating interest. But these are static rather than dynamic in their nature. The end gained is the maintenance of form, whatever the external stresses may be. But this is not effected by mere rigid resistance. Any wood exposed to a storm, or any meadow fanned by a summer breeze, shows how adult plants yield to the stress of wind, and how they recover perfectly when the air is still.

The original form is restored, notwithstanding occasional stresses from without. The plant-body is not constructed to produce dynamic effects of its own initiative, as animals habitually do, but passively to yield and later to resume the original form.
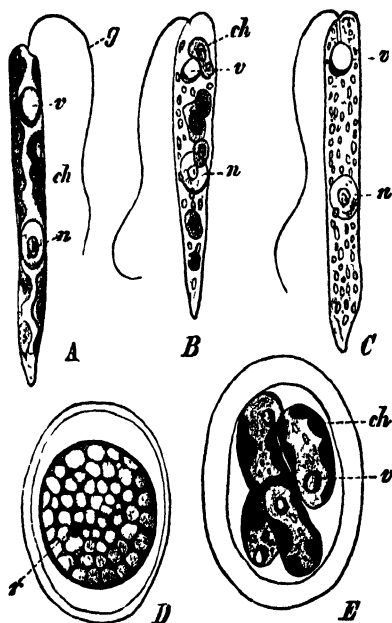
FIG. 75 --*A*, *B*, *C*, NAKED PROTOPLASTS OF *Euglena*, each with a lashing flagellum, by means of which it moves in water. *D*, *E*, encysted stage, with cell-wall, which is non-motile. The former may be held as a dynamic, the latter a static, condition. (From Strasburger.)

Structurally the two kingdoms parted company in the very first stages of their evolution. Indications of the divergence between the dynamic or animal-, and the static or plant-characteristics may be traced in the life history of very simple organisms. *Euglena*, that common denizen of manurial water, illustrates this. In early summer its bright green motile stage consists of a naked protoplast, bearing an actively lashing flagellum by means of which it moves rapidly in the

water medium. This may be held as a state pre-
figuring the dynamic animal. But as the season pro-
gresses another stage of existence is entered, in which
the organism loses its motility and secretes a super-
ficial shell or cell-wall. The flagellum is drawn in,
and the protoplast, no longer mobile, is described as
encysted. This state may be held as symbolising the
static plant (Fig. 75). All plant tissues are based
upon the encysted cell. The structural units of the
plant-body are each enclosed within a wall which
gives protection and offers resistance to stresses ; but
at the same time it imprisons and controls the active
protoplast. Liberty of movement has been sacrificed
to protection (Fig. 76). It is upon this plan that the
whole plant-body has been elaborated ; but in many of
the lower forms there is a recurrence to the dynamic
state in the motile propagative cells, which thus reveal
the probable source from which the static plant has
sprung.

The texture of any normally growing plant, con-
structed thus of encysted or walled cells massed to-
gether, is relatively firm and elastic, so that it keeps
its form, and after yielding to pressure tends to
recover. Even young shoots show this, but it is a
much more prominent feature in older parts. If,
however, the limit of elastic recovery is passed, any
part, young or old, may be so damaged that it is of
no further use to the plant. A trunk may be shattered,
a limb or a leaf may be severed and so lost, or soft
cells may be crushed between harder tissues, as may
be seen in any leaf-blade roughly folded at too sharp
an angle. To minimise such risks it is necessary that
plants shall be mechanically constructed so as to
resist all those stresses and strains that are likely to

befall them in their ordinary course of life.   This is
true for humble herbs ; but it is more impressively
evident in forest trees that grow upwards sometimes
to a height of 300 feet or more, and there hold aloft
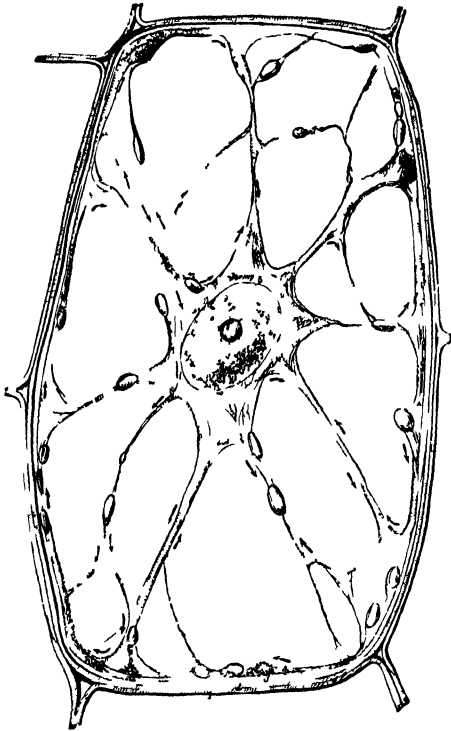
FIG 76   A VACUOLATED PLANT CELL HIGHLY MAGNIFIED   At
the exterior is the cell wall (shaded), which encysts the living proto
plast   The latter consists of a film of cytoplasm that lines the cell
wall internally and surrounds the large watery vacuole, while in the
centre the oval nucleus is suspended by threads of cytoplasm   The
arrows indicate the protoplasmic movements   Numerous chlorophyll
grains are seen embedded in the cytoplasm   (After Hanstein)
Highly magnified

the dead weight of branches, leaves, and fruits.   Not
only must this be done in still air, but they must also
be ready to resist successfully the impact of winds.
In large plants this presents a serious engineering
problem, and especially so in view of the fact that

perfect elastic recovery after the wind-pressure ceases
is a condition of its successful solution.   The neces-
sary firmness and elasticity of plants, whether large
or small, hard or succulent, depend in one way or
another upon the fact that a cell-wall surrounds each
soft and slimy protoplast (Fig. 76).

Every plant we see growing normally has solved its
own mechanical problem, or it would not be as it is.
One basal factor in the problem is economy of material.
This is as important in the construction of a plant as it
is in the construction of bridges or ships by the engineer.
In both cases the material is costly, while the less of
it that is used the lighter the structure will be.   In the
plant the material used is gained laboriously through
photo-synthesis.   The immediate end to be reached
is the formation of as large a vegetative system as
possible.   But this must be mechanically strong enough
to maintain its form.   Our chief interest will then be
to see how plants use their material to the best ad-
vantage.   It will be found that their methods often
run parallel to those adopted by Man to gain similar
results.   In plants there are two distinct methods of
securing high mechanical resistance together with
economy.   One is through the turgor, or internal fluid
pressure, of the individual cells ;   the other is by
tissues specially strengthened to resist strains.   The
former plays the chief part while tissues are young ;
the latter gives added strength to the mature parts.
Both of these methods may be effective in the same
part, and at the same time ;   but sooner or later
dependence on turgor passes gradually over to
dependence on the specific mechanical tissues, as
the shoot develops and the requirements become
greater.

Living plant cells are commonly characterised by a feature which may be held as a natural consequence of their encysted state, viz. turgor, or internal fluid pressure. The film of slimy protoplasm that lines the whole inner face of the cell-walls keeps it tight and stretched, as the inner tube of a pneumatic tyre presses on the outer cover (Fig. 76). The firmness of an inflated tyre depends upon air-pressure, as any limp deflated tyre will show. In the living cell the pressure is a fluid-pressure. But this difference does not interfere with the mechanical result. The hydrostatic turgor, or internal fluid pressure, of the individual cells gives firmness to a tissue composed entirely, or at least chiefly, of cells. A Lettuce, for instance, freshly cut from the garden will be crisp and resistant. But let it lie exposed to the air on a hot day and it will soon become limp and flabby, and finally shrivel. Such withering is the result of evaporation of the contained water, with a consequent diminution in the turgor of the cells, and loss of mechanical firmness follows. But just as the deflated pneumatic tyre may be restored by the pump, so the turgor of a withered shoot may be restored by forcing in water under pressure at the cut surface of the stem. The water thus injected is absorbed by the individual cells, and they resume their normal state. Such turgor is a feature of living plant-cells, and is indeed a vital function. It depends upon the fact that each cell contains a central vacuole, or cavity, in its protoplasm, filled with water having osmotically active substances, such as sugar, dissolved in it, while the living protoplasm surrounding the vacuole prevents their escape (Fig. 76). These solutions are osmotic, that is, they tend to absorb water, thus increasing their volume till the resistance of the

stretched cell-wall balances the osmotic pressure (Fig. 77). This balance is struck at pressures which may be equivalent to several atmospheres, varying from 5 in ordinary cells to 20 in extreme cases. But it may be objected that such pressures as these, the equivalent of 150 to 600 inches of mercury, could not surely be resisted by thin cell-walls. Can the calculations be really correct? In explanation it is to be remembered that the cells themselves are minute, and that what might be palpably impossible in a large cell is quite within the range of possibility where the cells are microscopic.

In the chapter on Garden Vegetables it was stated that a fresh Lettuce may consist of about 94 per cent. or more of water, and only about 6 per cent. of the materials of cell-wall, protoplasm, ash, etc.; and yet it is firm and crisp, showing how great is the resistant power of the cell-walls. This extreme instance shows how efficient the turgor of thin-walled cells may be in giving mechanical stability. Not only is the form stable, but the leaves are sufficiently stiff to resist wind pressures. Nevertheless, only a small fraction of the whole weight is devoted to the material framework upon which the stability depends. Much has been written on the marvellous

FIG. 77. AN INTERNODAL CELL OF *Nitella*: *s.s.* lateral segments cut short; *F* shows a single cell fresh and tur gescent; *p* shows the same cell with the turgor reduced; it is now flaccid, shorter smaller, while the protopla has separated in folds from the inner surface of the cell wall, which it no longe stretches. (× 6.) (Afte Strasburger.)

planning of the honeycomb and the drastic economy
of substance observed in its construction. Surely here
is something quite as wonderful. In this instance,
however, the stability does not depend, as in the
honeycomb, upon the rigidity of the walls of the cells,
but upon their elastic resistance to the turgor origi-
nating from the cell contents. Moreover, a honey-
comb has only to maintain its form in still security ;
the delicate framework of the Lettuce has to uphold
itself against winds, and resist the leverages following
on exposure of large leaf surfaces to their impact,
while the framework involves less than 6 per cent. of
the total weight. Clearly, good use has been made
here of a very limited amount of material.

By far the greater part of the tissues forming young
succulent or herbaceous shoots is made up of thin-
walled cells turgescent during normal life. But there
is a further circumstance that contributes to the sta-
bility and firmness of stems and leaves so constructed.
It is that the tissues that build them up are not all in
passive relation to one another. They are themselves
subject to mutual tensions. In particular, the central
mass of pith in a young stem is always tending to
elongate, owing to the internal pressure of its indi-
vidual cells. On the other hand, the adjoining tissues
forming the outer layers and finally the superficial skin
of epidermis are stretched tight, offering resistance to its
strong impulse to extend. A very simple observation
will suffice to prove that this is true (Fig. 78, 2a, 2b).
If by longitudinal cuts you split the stalks of flowers
that you are going to keep in water, as is habitually
done by those who know how to make them last, you
will see (provided that they are fresh) that the separ-
ate sectors will curve outwards, the external surface

will then be concave, and the internal convex. The curvatures come out more clearly if the cut stems be allowed to stand in water for a short time. Soon the inner tissues will have expanded, and, in point of fact, the outer will have contracted whenever they became free to do so. The point may be even better demonstrated in another way. If the stem of a Sunflower, or some other sappy stem, be transversely cut to a smooth surface, and then the central column of pith be separated from the outer-lying tissues by the circular cut of a cork-borer or a cheese-taster, and the stem so cut be allowed to settle in water, the central column of pith, freed from the restraining outer tissues, will project some distance from the originally smooth surface (Fig. 78, a). Previously it had been compressed, and when freed it elongates. Imagine it now put back to its original state. The pith will have to be compressed and the outer tissues stretched. This is in fact the state of those tissues in ordinary stems. The mechanical relation is somewhat like that of the mast and standing rigging of a ship. But there the shrouds are sweated down, while in the plant the mast (*i.e.* the pith) is growing! In both cases tension, and the consequent mechanical stability, are the result.

FIG. 78.—*a*—SHOOT OF SUN FLOWER WITH ITS PITH SEPARATED BY A CORK-BORER FROM THE OUTER TISSUES. 2*a* a split stem of Dandelion; 2*b* the same after immersion in water. (After Strasburger.)

There is, however, another feature in which the metaphor of the mast and rigging does not so nearly

tally with the relation of the tissues in the growing stem. There is in many herbaceous stems and leaf-stalks, such as the Potato or Sunflower, a tissue called the collenchyma because of the gummy nature of the thickened cell-walls (Fig. 79). It forms a peripheral sheath just below the epidermal skin. This tissue offers steady resistance to the elongation of the pith, but as constantly it yields when the strain is too great
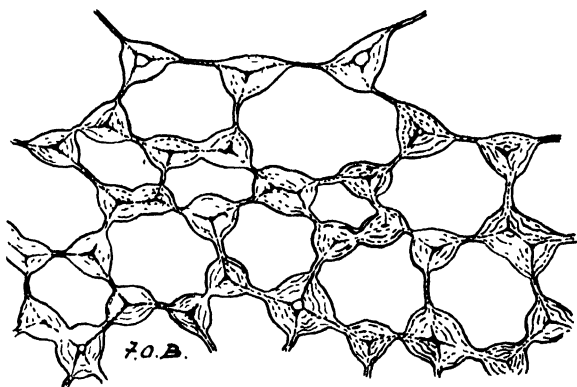
FIG. 79.—TRANSVERSE SECTION OF THE WALLS OF CELLS OF COLLENCHYMA FROM THE STEM OF THE POTATO. (300.) The cell-walls are of cellulose, and are specially thickened at the angles where the walls meet. (See Text)

for its resistant gummy walls. The relations between the two are like those of the first and second chambers in the constitution of a state. The first chamber urges reforms, the second chamber resists ; but if the initiative be continuously pressed it yields. Meanwhile stability is maintained in the growing commonwealth, as it is mechanically in the growing stem or leaf.

Sooner or later any given region of the sappy, growing shoot completes its increase in length. No doubt the gradual thickening of the walls in the maturing tissues will offer a constantly increasing obstacle to

the driving force of the pith, while the latter of itself weakens with age. And so the stem enters the rigid state of the adult. As this change comes on the mechanical strength of the whole increases, while the onus of its stability passes from the delicate turgescent cells to those tissues specifically developed to bear it by reason of their thickened walls. The nature of these tissues, and the methods seen in their arrangement, so as to obtain the greatest mechanical effect with the least possible expenditure of material, will be the subject of the following chapters. But in the first instance the mechanical resistance of all young parts of plants depends upon the turgescence, or internal fluid pressure, of the individual cells.

CHAPTER XVIII

MECHANICAL CONSTRUCTION OF PLANTS

(B) The Columnar Stem

A PRIMITIVE obelisk : a tower with or without a spire, and buttressed at its base : a factory chimney, or a lattice-girder-scheme such as that seen in the Eiffel Tower, illustrate the methods of Man in penetrating to levels high above the earth's surface. When he wishes to uphold sails or a flag against the pressure of winds he often uses the trunks of trees as flag poles or masts, thus adopting the mechanical methods of Nature herself at second hand. Latterly, as in masts of large ships and in wireless stations, he has substituted for wooden spars metal structures scientifically designed to meet the greater requirements. But usually such " masts " are upheld by stays, or standing rigging. By these means he may successfully attain heights of several hundred feet. The mechanical problem which he solves in one or another of these ways is essentially the same as that presented by any upward-growing plant, and it will be seen as we examine the columnar stems of herbs, shrubs, and trees that the methods adopted by plants in its solution are often closely like his. But here external stays and standing rigging play no part. Moreover, when

it is remembered how great is the dead weight of the branches and the collective area of the leaves, and that these must be upheld against the impact of wind from any quarter, the engineering problem involved in the construction of a large tree, or of any smaller shrub or herb, acquires an interest certainly not less than that in the engineering works of Man.

A first illustration of the mechanical construction of a plant-stem may naturally be taken from that which is most familiar, viz. the trunk of a tree such as the Pine or Larch, Oak or Sycamore. Its form is roughly conical, with its apex pointing aloft and its base at the level of the soil. The base is naturally the oldest and thickest, and the slender apex the youngest part. The upward tapering form is due to the activity of a tissue called the Cambium, which forms a mantle all round the stem, lying a little beneath the outer surface. It is easily recognised in spring by the fact that being then soft and readily ruptured, the shell of tissue outside it, often incorrectly called bark, may then separate, leaving the central woody column exposed. Each season a zone of fresh wood is added by the Cambium on the outside of that column, so that the trunk grows in thickness from year to year, acquiring added strength to uphold the growing head of branches, twigs, and leaves above. Each branch follows the same model, and so increasing as the requirements themselves increase, due stability and resistance are secured. The principle of construction in such woody trunks is that of the solid column, acknowledged by engineers to be not the most economical mode of use of material. Excepting for stone buildings it is rarely adopted now in the larger works of Man, and accordingly it may be thought

that Nature is behind him in engineering method. But those who would argue thus omit to notice that mechanical support is not the sole function of the woody trunk. The problem of the tree is a complicated one. The trunk has to convey water and salts
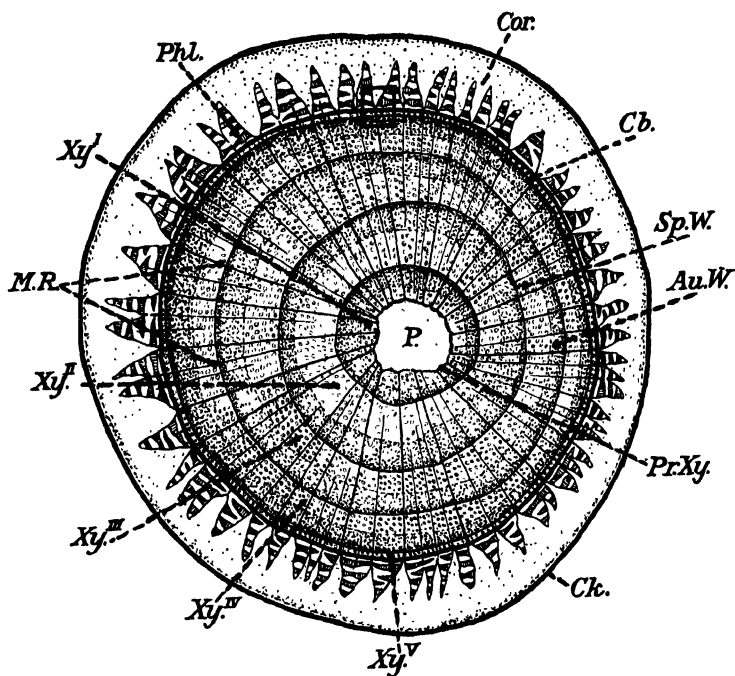
FIG. 80.—TRANSVERSE SECTION OF A STEM OF LIME, cut in the spring of its fifth year. P=pith; Xy^I-Xy^V=the successive rings of wood from the first to the fifth year, Xy^V being narrow because the stem was cut before the woody ring was fully formed. The wood together forms an almost solid column. ($\times$ 12.)

from the root upwards, and elaborated food downwards during life ; and it has also to serve as a place of storage of materials for the supply of new leaves and shoots in the spring. That solid column, which the engineer may despise as a structural back number, is required to do duties from which his more elegantly constructed columns are wholly free. The marvel is

that organic Nature has solved at all the complex problem of supplying in a single structure not only mechanical strength, but also transit of materials and space for storage, and that the column should still grow continuously, meeting as they arise the changing requirements of the ever-enlarging tree.   Engineers have never devised such a thing as this.
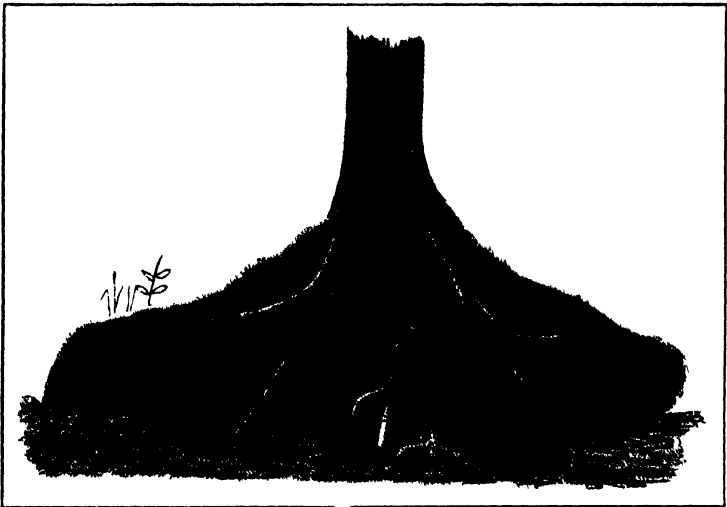
FIG. 81.   BASE OF THE STEM OF *Sterculia* IN THE BUITENZORG BOTANIC GARDEN, showing buttress-like roots supporting its base. (After Haberlandt, from Schimper)

The head of branches and leaves upheld above offers a large surface to winds, and the leverage at the base of the firmly rooted conical stem is great.   Particularly will this be so in tall trees, such as those of Brazilian forests, where the canopy may be 200 or 300 feet above the ground.   The special demands made by this leverage at the base are often met by a graceful basal curve, in outline like that at the base of the Eiffel Tower.   Flanges of greater thickening may there be seen radiating out from the central trunk

and extending downwards to the main roots. Our larger native trees show this in some degree, but tropical forests supply many instances of so-called " buttressed " trees, with deep radiating flanges that act mechanically like the buttresses of a gothic tower. (Fig. 81). They suggest what there is some reason for believing to be the actual truth, that the amount of resistant tissue formed depends directly upon the requirements.

The stems of herbaceous plants, such as the Sunflower or the Bean, are constructed on the same general
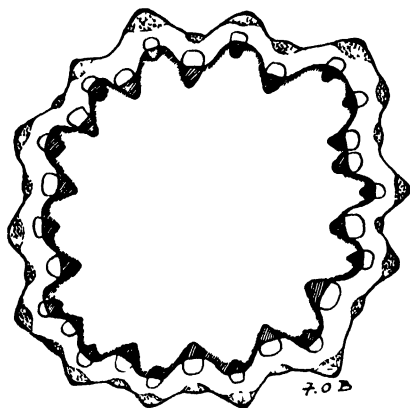
FIG 82 – TRANSVERSE SECTION OF THE FLOWERING STEM OF *Astrantia* The collenchyma is dotted. The vascular bundles form a ring surrounding a very bulky pith.

plan as trees. But they have a large proportion of soft, sappy tissue, through which the fibrous vascular bundles take a longitudinal course. These are usually ranged in a cylinder round the central pith. The whole structure is mechanically comparable to a ferro-concrete column : the stringy and resistant bundles represent the reinforcing metal bands and the sappy tissue the concrete (Fig. 82). But in the stem there is this great advantage over the rigid concrete of the

builder : that the softer tissues can yield, and to some extent the stringy bundles also, and so the column can curve within limits under strain, recovering when the pressure ceases. So far then from the recent introduction of ferro-concrete into construction being a new invention, plants had already adopted the principle on a more elegant basis than the architect, and it was in full working order in their stems and leaves long before the advent of Man upon the earth.
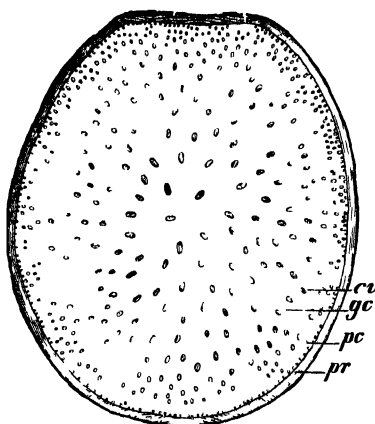
FIG. 83. TRANSVERSE SECTION OF AN INTERNODE OF THE STEM OF MAIZE which illustrates the Palm type of construction. *pr* primary cortex; *c* vascular bundles which appear isolated and scattered through to the centre; *gc* soft ground parenchyma which embeds them. (After Strasburger.)

In Monocotyledons, such as Palms and Bamboos, and in Grasses generally, the mechanically effective material is used to better advantage than in broad-leaved trees and conifers, and the whole structure is consequently lighter than in their solid trunks. Palms bear a large terminal tuft of leaves, and often attain great height. (See Fig. 22. p. 48). Their cylindrical stems are found to have the most resistant tissues massed towards the outside. while the whole central region is softer, though permeated by numerous

vascular strands whose cut ends appear scattered throughout the transverse section (Fig. 83). But if the strands are followed in their longitudinal course they are seen first to arch inwards from the leaf-bases towards the centre of the stem, and then with a slightly spiral lateral curve to pass obliquely outwards again towards the hard external rind, where they finally fuse. Cut transversely and smoothed, the hard outer tissues of a large Palm stem take a fine polish, but the softer tissue within is friable when dry. The isolated vascular strands often stand out like stiff wires from the softer medium they traverse, reminding one again of reinforced concrete.

The leverage on a tall Palm stem when the wind catches the terminal tuft of leaves is enormous. The strain is like that on the unstayed mast of a Scottish keel-boat. The resistance will arise chiefly from the outermost cylinder composed of vascular strands embedded in hard mechanical tissue. The risk of " buckling " is here met by the cylinder being filled with solid though less resistant tissue traversed by the arched strands, which, with their spiral curve, make up a system capable of yielding to stress and recovering. The mechanism as a whole is roughly like certain supports for railway bridges (now discarded), where a cylinder of metal was filled with a grouting of concrete, or like the marrow-bones of mammals ; but here the hard superficial bone surrounds the marrow that is relatively soft. Such structures are designed to meet the stress of dead weight ; but the Palm stem is constructed to give elastic resistance also under lateral strain, and in this its beautiful construction is highly successful.

Clearly as long as " buckling " can be avoided the inner grouting of the cylinder is a burden rather than a mechanical advantage, for it adds greatly to the weight of the structure. Many stems do away altogether with the central tissue, thus resembling the
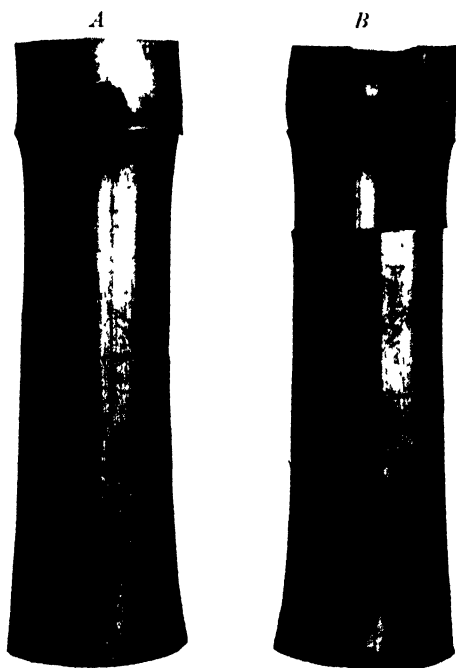
FIG. 84.—PIECE OF A STEM OF A BAMBOO, INCLUDING ONE NODE AT ITS UPPER END In *A* it is seen from the outside, with a transverse scar of the leaf-insertion, and a circular scar of its axillary branch. In *B* it is cut so as to show the central cavity, and the septum, which gives added strength to the cylinder. (Reduced to ⅓)

hollow bones of birds, which are constructed on a plan that secures both efficiency and lightness (Fig. 84). The hollow column applied in so many of the affairs of life is the response of modern Man to these two demands. But here a stiff resistance is the end rather than that yielding and recovery as by a spring, which is the essence of plant-

construction It is to the Grasses that we may look
for the most beautiful examples in the realisation of
this ideal. A field of waving corn is not merely a
delight to the eye, but to the intellect which looks
beyond the scene as a whole to the mechanism which
underlies it The Grass-haulm is one of the most
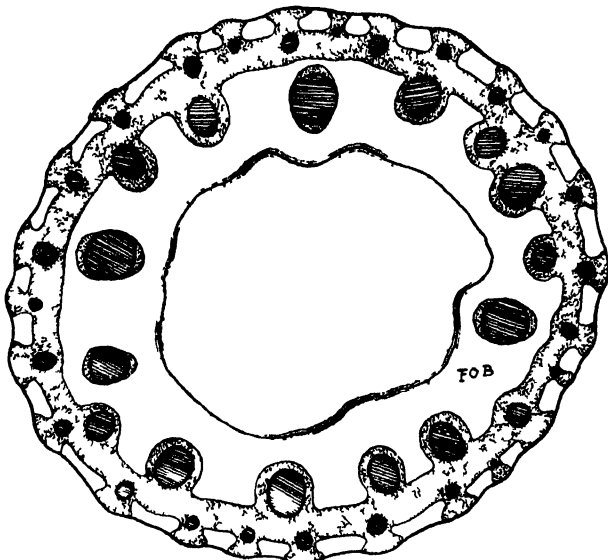
FIG 86 TRANSVERSE SECTION OF THE FLOWERING SHAFT OF
Molinia caerulea Centrally is a large cavity The thin walled
tissue is left clear the hard mechanical tissue is dotted and the
vascular strands cross hatched The peripheral strands are em
bedded in a continuous ring of mechanical tissue The structure is
that of a hollow cylinder fluted within and without (40)

wonderful things in organic Nature (Fig 85) Mag-
nified to the size of the Giant Bamboo, which is also
a Grass, though over 100 feet high, it impresses the
mind as an imposing mechanical triumph (Fig. 87, p
217)

Grasses are plants in which the leaves are regularly
alternate , they stand right and left of the stem which
bears them, so that the third is always above the first.
Each leaf has a sheathing base that enwraps the stem,
and its insertion on the stem is called a node The

stem is cylindrical and elongated, so that the leaves
are separated by spaces or internodes, longer or shorter
according to the circumstances.   The growth in length
of each internode takes place at its base, and as the
tissues are necessarily soft while growth is in progress,
these weak spots are protected and upheld by the
closely fitting leaf-sheath, which is often specially
strengthened so as to give support like a bandage.
But the stem hardens as it matures, so that the whole
length of " straw " finally becomes firm and resistant.
Each stem is thus a hollow tube, plugged at intervals
by firm transverse plates or septa, one of these occur-
ring at each node.   The mechanical resistance is
supplied chiefly by the wall of the tube.   A hollow
tube under strain is always liable to buckle,
owing to collapse of the cylindrical form.   To meet
this risk it must be propped out at intervals, as the
haulm is, by the firm transverse septa.   The nearer
these are together the stronger the construction
will be, and as a matter of fact they are nearest at
the base, where the leverage is the greatest (Fig. 86).
Elongation, so as to raise the flowering stem to a
free exposure above the surrounding herbage, is an
advantage for these wind-pollinated grasses ;   there
is thus a premium upon long internodes.   Each
plant must strike a safe compromise between
mechanical risk and upward growth.   Many a corn-
field after a storm, just before harvest, shows in the
" lodged " crop clear evidence that the margin of
safety against rough weather had been overstepped.

The fruiting stem of a native grass, *Molinia coerulea*,
is a good example of the actual dimensions involved,
which will give some estimate of the effective use of
the materials in securing high mechanical results.   In

the fruiting state it bears erect or nodding the weight
of the matured grains. The mechanical tissue forms a

FIG. 86. PHOTOGRAPH SHOWING THE BASES OF BAMBOO STEMS
WHICH MAY GROW OVER 100 FEET HIGH. The stems are marked by
rings each of which is a leaf insertion, and the hollow stem is there
supported by a hard transverse plate or septum. Note that at the
base where the leverage will be greatest the septa are nearest to-
gether so that the resistance will be greatest there. One of the
young conical shoots has been cut so as to show the septa crowded
before the shoot has elongated.

continuous cylinder, with septa only at long intervals
(Fig. 85). At its base it may be about one-sixteenth

of an inch in diameter, but it is there supported in some degree by its sheathing leaves. It may grow to a length of 30 inches before bearing its inflorescence. Thus the length of the stem is to the diameter as about 500 to 1. In the same proportion as in the *Molinia* stem, the spire of Salisbury Cathedral would be less than one foot in diameter at its base, which would be a physically impossible proportion for a structure of that size, built of stone. The fact is that while this extreme proportion of length to diameter may suffice for a small Grass, it cannot be maintained indefinitely for larger Grasses: much less for a church tower. The mechanical insufficiency is enhanced where structures are larger, less scientifically planned, and of baser materials. There is a limit of size beyond which it becomes impossible for a certain type of structure, built of given materials, to maintain its form. For instance, a Giant Bamboo, constructed on the same plan as *Molinia*, may be as much as 35 metres high and 30 cms. in diameter at the base (Fig. 87). But that is a proportion of only about 116 to 1. Though these proportions are less striking than those of the smaller *Molinia*, yet for a plant of the size of a Giant Bamboo its dimensions have been calculated as about the limit possible. If the limit be exceeded the structure will bend or break. In the Bamboo, which approaches that limit, the extreme top does bend in a graceful curve, owing to the weight of its leaves and distal twigs (Fig. 87). So do also the haulms of most Grasses, which, like *Molinia*, approach each their own limit of mechanical resistance resulting from their actual dimensions and structure.

While the stems of Monocotyledons thus provide the most elegant examples of the use of the available

materials so as to develop a high mechanical effect, the stems of some Dicotyledons show similar devices.
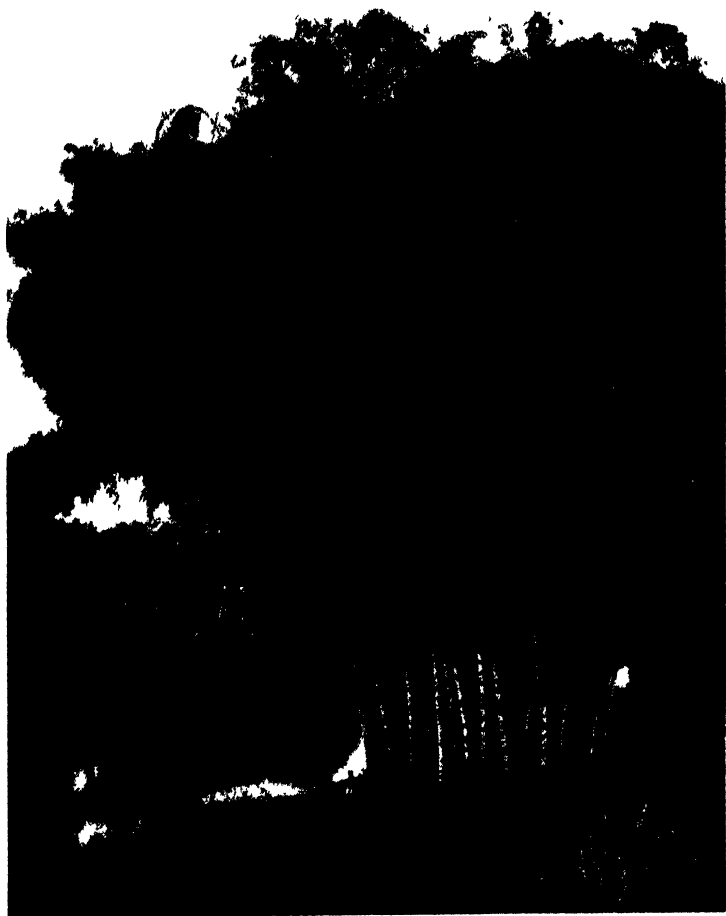
FIG. 87.—GROUP OF GIANT BAMBOOS (*Dendrocalamus gigantu*)
IN THE ROYAL BOTANIC GARDEN, PERADENIYA, CEYLON   Note the
man at the foot of the clump which gives the scale : also the succes-
sively shorter internodes at the base of the stems, and the curvatures
above   (After Schimper)   Compare *Frontispiece*, and Fig. 86.

The resistant tissue is massed as near as possible to the outer surface, in their hollow and partitioned

stems, as is seen, for instance, in the Hemlock (compare Figs. 82 and 85). There is no reason to suppose that such similarity of structure, appearing in families so diverse as the Grasses and the Umbelliferae, is in any sense a common inheritance. It is practically certain that these are results of parallel adaptation to circumstances ; in fact, they illustrate what evolutionists call homoplasy, that is, the attainment of a similar form and structure independently in two or more quite distinct evolutionary lines. It is not in stems only that the mechanical construction of plants follows recognised engineering principles, and has achieved highly efficient results. It will be seen in the next chapter how leaves and roots afford other, and even more curious, parallels with the mechanical methods adopted by Man.

CHAPTER XIX

MECHANICAL CONSTRUCTION OF PLANTS

(C) THE LEAF AND THE ROOT

WHILE the stem is usually an upright column, the leaf is habitually flattened and its blade is placed horizontally, one face being turned upwards to the sky, the other downwards. It thus acts as a sun-trap carrying on nutrition under the influence of light, as explained in a previous Chapter. The larger the area of the blade exposed the greater will be the amount of the food acquired. The problem will therefore be to secure as large a leaf-area as possible with reasonable security against mechanical and other risks. On grounds of economy this must be carried out with the least possible expenditure of material. Apart from the mere mechanical support of its own weight in still air, the leaf will have to resist undamaged the pressure of winds, and maintain its tissues functionally unimpaired by them. To meet these complex demands the leaf exhibits a surprising series of structural adaptations, most beautiful in their varied efficiency.

The leaf, like the stem, adopts a method of yielding to pressure and recovering the original form whenever the pressure passes off. A spring mechanism is

brought into play. The resistance offered increases as the part by yielding changes its form up to the limit of elasticity. If this be overstepped permanent damage is the result. In leaves the injury takes the form of crushing the softer tissues between the harder layers or strands ; or of tearing inwards from the margins of the flattened expanse, so as to expose the inner tissues, or in extreme cases reducing the blade to tatters. Such marginal tearing is habitually seen in the large leaves of the Banana when it is grown in the open. That this is un-common among plants at large is in itself evidence of the efficiency of the methods of the mechanical construction of their leaves, and of natural selec-tion in weeding out the unfit.

FIG. 88 —TRANSVERSE SECTION OF A PETIOLE OF THE SUNFLOWER, showing the grooved upper sur face, and the convex lower surface strengthened by collenchyma, which is dotted. The whole struc-ture appears like a sector of the Sun-flower stem (6)

The most obvious provisions against damage of the leaf are those of external form, and particularly the division of the blade into segments, which is carried out in various ways (compare Fig. 5, p. 13). The distinction itself of stalk and blade, which is so common though by no means universal, makes easy the yielding of the expanded blade, by change of form of the often long and flexile stalk. Sometimes it lends itself specially to this ; a glance at the leaf-stalk of the Aspen, with its sides so flattened that it appears as a ribbon placed vertically on edge, explains the shivering of its leaves before the gentlest breeze. But commonly the leaf-stalk is relatively firm. Its chan-nelled upper surface, giving a half-moon shaped transverse section, is clearly in relation to the support

of the heavy blade (Fig. 88). Resistant conducting strands pass from end to end of the stalk, and it is strengthened by firmer tissues at the surface. Thus constructed it resembles the stem itself, and often corresponds structurally to a sector of it. Though the leaf-stalk may at times appear to be relatively stiff, it is still capable of yielding in some degree as a consequence of its length, and of its compact and channelled form.

It is, however, in the structure of the blade that the leaf commands more special interest (Chapter II). The spongy, thin-walled green mesophyll is mechanically weak, while its cells being full of water it is relatively heavy. If this actively living but mechanically weak tissue is to be exposed in the most advantageous way to the light and air, it should be spread out as a thin sheet. Clearly this by itself would be mechanically impossible. But it is enclosed above and below by the continuous and transparent epidermis, which provides a firm outer skin covered by the water-tight cuticle. This binds the loose mesophyll together and compacts the wide expanse of the blade. The whole is still further strengthened by the system of veins, forming that resistant skeleton which is often seen isolated by decay of the softer tissues. Its mechanical duty is like that of the frame of an umbrella, and like it the skeleton may remain after the cover has perished (Fig. 89). Leaves show marked differences in the disposition of their veins : for instance, those of Dicotyledons have usually a strong midrib with less strong branches running from it right and left, which may branch repeatedly again, while the veinlets fuse freely to form a network usually closely meshed. In the Mono-cotyledons the chief veins are of almost equal size,

and run longitudinally with a parallel course, but they
also are linked together by thinner transverse branch-
lets. In either case the veins form a connected
system, serving the double purpose of conduits con-
veying material to and from the active mesophyll, and
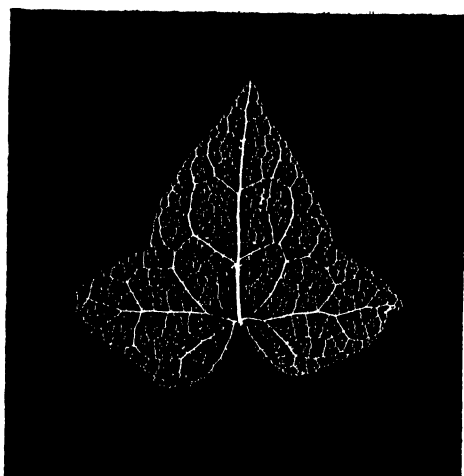
FIG 89 —SKELETON OF LEAF-BLADE OF THE IVY NATURAL SIZE.
The reticulate venation shows intra-marginal arches.

of giving mechanical support. This latter duty the
larger veins are the better fitted to perform by pro-
jecting as strengthening ribs from the lower surface of
the blade, while bands of firmer tissue often accompany
them above and below (Fig. 90). Lastly, as we
have seen, the tissues are all held together by the firm
epidermal skin, so that the blade is a reasonably strong
structure. It is essential that it shall be so far stiff-
ened that it shall retain as nearly as possible its
flattened form. In particular it must be strong enough
to prevent any violent gust of wind from throwing it
into so sharp a fold that the softer tissues should be
crushed between the harder. The damage that may

be done is easily illustrated by folding the blade of a leaf sharply between the fingers, when the line of crushing is marked by discoloration and the blade does not recover its form. In normal life this must not occur, and the blade is so constructed as to prevent it.

Monocotyledons such as the Grasses offer the best illustration of the flattened blade structurally stiffened.
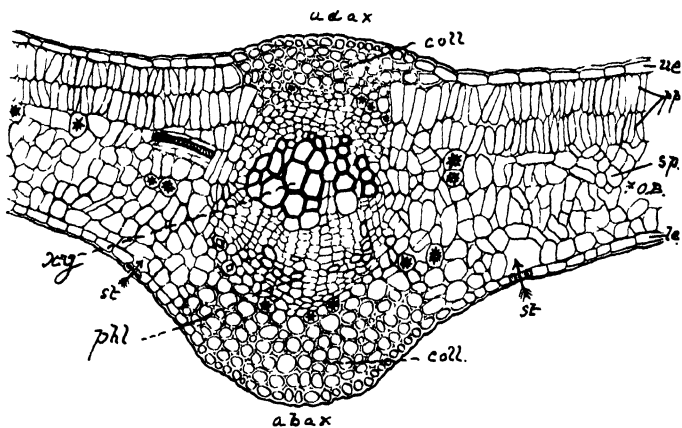
FIG. 90.—TRANSVERSE SECTION THROUGH THE MIDRIB OF THE LEAF OF ASPEN, and extending to the thinner expanse of the blade right and left. Note the softer mesophyll within (pp, sp); the firmer epidermal layers (ue, le) that bind it together; and the strong midrib, with bands of collenchyma above and below the vascular strand. (75)

It is easily apprehended in them because their veins being parallel, the scheme appears more regular and intelligible ; but partly also because they secure more perfectly perhaps than any other plants a high mechanical effect, together with economy of material. The method is structurally similar to that seen in any girder bridge, where also stiffening of a flat structure is required so as to support the traffic. It has been noted that in grass-leaves bands of firmer tissue commonly accompany the parallel veins above and below. These bands consist of hard, resistant fibres of great

tensile strength. They lie as far apart as the thickness of the leaf will allow, just beneath the epidermis which, being itself hardened, is often fused with them. Being opposite one another, with less-resistant tissue between them, each pair constitutes, not in imagination only but in actual fact, a girder, comparable from a mechanical point of view to a double
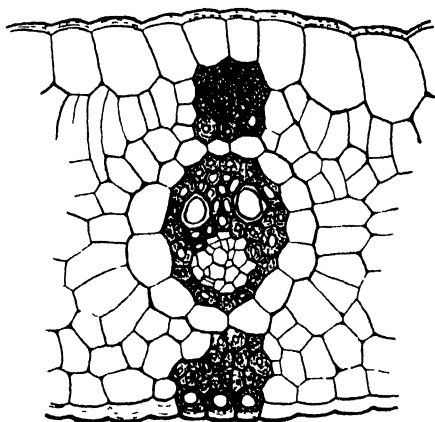
FIG 91 —TRANSVERSE SECTION THROUGH THE LEAF-BLADE OF CYPERUS, A MONOCOTYLEDON showing a vascular strand with straps of hard resistant tissue above and below it. These together constitute a girder, which is held in its place by being embedded in the surrounding tissues   (300)

T girder such as is used in bridge-building or in supporting floors, etc. (Fig. 91). The success of a girder depends upon its being firmly fixed in the best position to resist the strain. These girders of the leaf are held in the most advantageous positions relatively to the flattened surfaces by being built into the softer tissues of the blade. As the veins run parallel, the whole girder-construction of the leaf-blade resembles that of a railway bridge, such as the older part of the bridge leading out from the Central Station in Glasgow, or from Charing Cross in London. The trains traverse a space between the

deep girders ; the corresponding space in a grass leaf is filled with the soft tissue of the mesophyll. A like structure appears in many other leaves than those of Grasses. Those of broad-leaved trees and of Ferns show girder-construction, and even ancient fossils of the Coal Period do the same. Thus the principle of the girder was no new invention of Victorian Engineers, but was in practical use in the plant body long before Man appeared upon the Earth.
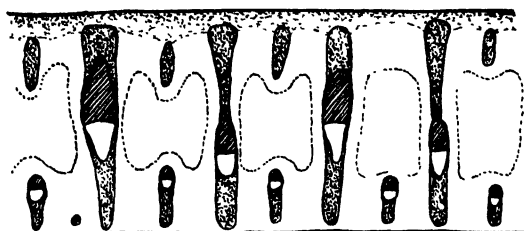
FIG. 92.—TRANSVERSE SECTION OF THE LEAF OF THE NEW ZEA-LAND FLAX (*Phormium tenax*), A MONOCOTYLEDON. The thin-walled tissues are left clear ; the areas in dotted outline are soft aqueous tissue ; the mechanical tissue is dotted, and the wood cross-hatched The whole shows an elaborate girder-construction, held together by the epidermis and softer tissues (×20.)

The stresses which would lead to tearing of the leaf-expanse from the margin inwards are almost as great a source of danger from exposure to winds as those met by the general stiffening just described. The risk is the same as that to which textiles are liable. In ordinary life these risks are met either by a selvedge or woven border, where the threads of the cloth are continuous, but curved on themselves ; or by a hem ; or by gussets. Often the latter are combined in ordinary clothing. The hem is used to strengthen the continuous margin by doubling it over and sewing it ; the gusset is inserted as a triangular patch at the base of some indentation, so as to meet the risk of tearing inwards from the weakened point. It is

interesting to see how closely these familiar methods coincide with the marginal strengthening of the leaves in the most various plants.   Arched selvedges are
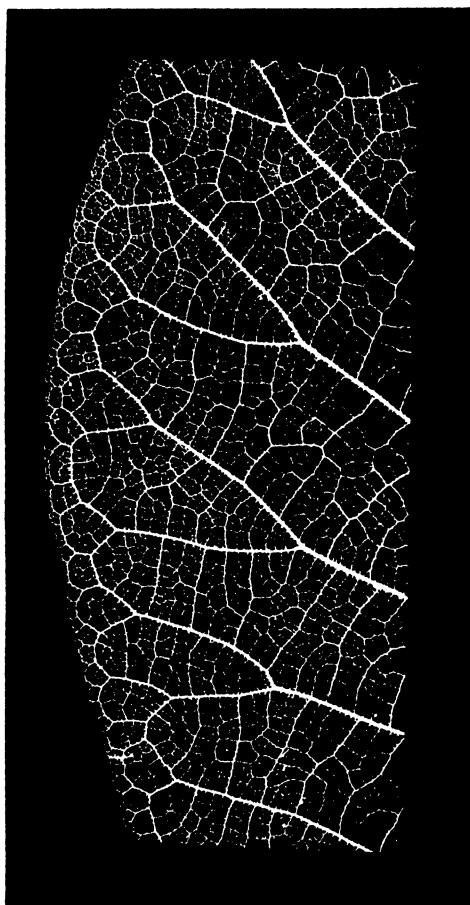
FIG. 93.—PHOTOGRAPH OF A SKELETON OF A DICOTYLEDON LEAF, showing its reticulations with successive series of intra-marginal arches.   (Natural size.)

a common feature in the leaves of Dicotyledons (Fig. 93).   The network of veins consists of stronger and weaker strands.   The stronger are frequently seen describing broad intra-marginal archings, succeeded by others of smaller curve still nearer the margin.   The

curve of each arch runs for some distance parallel to
the leaf-margin, which is thus strengthened in a
manner closely like the selvedge of woven cloth.   The
parallel venation of the leaves of Monocotyledons acts
in the same way, the most marginal strand being
actually a single long strengthening arch.   But a
more effective method is by a band of hardened tissue
occupying the margin itself, taking mechanically the
place of the hem of a garment or kerchief.   Such
common leaves as those of the Sycamore and Elm show
this, as well as the leaves of Palms and of Gum-trees
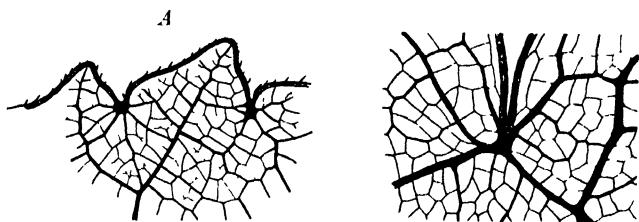
FIG. 94. –SMALL PARTS OF THE LEAF-BLADES OF THE ELM (A),
AND SYCAMORE (B). In each there is a mechanically strengthened
margin, which expands into massive " gussets " at the base of the
indentations, where they also join up with the reticulate venation.
(14)

(Fig. 94).   Finally, the gussets of our clothing find
their parallel in patches of hardened tissue that are
frequently seen at the base of those deep cuts so
often present at the margins of leaves.   The Elm and
Sycamore both show them as pronounced thickenings
of the firm marginal band.   But they are some-
times present where the rest of the margin is not
thickened.   Good instances are seen in the leaves of
some Ferns (Fig. 95).   From what has been said it
is clear that the leaf-blade presents many points of
interest in its mechanical construction.   While the
requirements are the same as those met in ordinary
life by mechanical devices such as those quoted,

they are met in plants by devices that are strikingly similar in their essence, though differing entirely in their actual details.
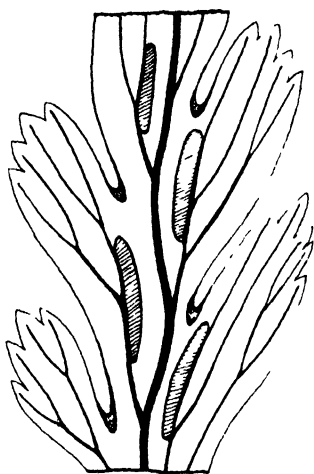
FIG 95 PART OF A LEAF OF A FERN (*Asplenium horridum*), showing " gussets " of hardened tissue, one at the base of each of the indentations of its margin They are quite separate from the veins (Slightly enlarged)

Roots which hold the columnar stem upright against the impact of winds are subject to quite different strains from ordinary stems or leaves. They must resist longitudinal tension, as on a rope or string. In cordage the fibres are twisted together ; one consequence of this is that they are grouped in a small area of transverse section. This method secures the even distribution of the strain over them all, with increased probability of successful resistance. A similar condensation of the mechanical tissues, but without the twisting, is usual in roots ; they form a central core, and it is frequently pithless, lying surrounded in the young root by soft mechanically ineffective cortex : a structure very different from that of the stem with its circle of strands widely distended (Fig. 96). The difference in structure accords with the difference in the mechanical requirements of the two. But in some stems the rope-requirement does exist : for instance,
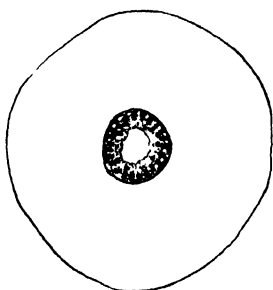
FIG 96 TRANSVERSE SECTION OF A ROOT OF *Ruscus*, showing the large proportion of soft cortex to that of the contracted and pithed stele (× 12).

in the Sand Sedge and in the Marram Grass, two of
the most effective plants in binding shifting sands,
and they are liable to longitudinal tension in the doing
of it.   Though not closely related, in both of these
the broad cortex is weak and has large intercellular
spaces, while the vascular tissue is compacted at the
centre and cemented together with hard woody fibres,
so as to form a solid core, so different from the
aerial stems (Fig. 97).   Stems supporting heavy
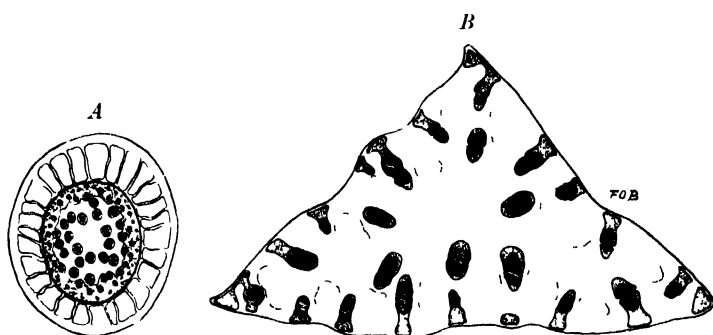
FIG 97 – SECTIONS OF THE STEMS OF TWO SEDGES.   A   Rhizome
of *Carex arenaria* with the mechanical tissue condensed centrally,
so as to resist like a rope or cord.   (14)   B   *Carex vulgaris*, the
upright stem of which has to support weight and resist winds, with
its resistant strands at the surface and angles of the section. (×25.)

pendent fruits show a like structure, as well as some
submerged stems which are subjected to longitudinal
strains by flowing water.   The similarity of these
modifications of structure in plants of such various
affinity, when subjected to the same mechanical
demand, shows that the concentration is adaptive.

    There is good reason for believing that the mechani-
cal construction of the plant-body, such as has been
above described, has come into existence in the course
of Descent, and in accordance with the requirements:
in fact, that it is the result of adaptation.   As a rule the
structure is hereditary, though experiment shows that

the conditions to which the developing parts are exposed may influence the quantity of the hardened tissue formed, increasing or even stimulating its formation. But experiment will not explain the origin of the specific methods of its distribution. The degree of parallelism which those methods show to the methods of engineers in using their stone, steel, and concrete is remarkable. While we admire the efficiency of the result in either case, and especially the economy of material made possible by those methods, it is to be remembered that the priority of initiative undoubtedly lies with the plant. For many of the methods represented in ancient fossil plants have been adopted by Man only in the last few decades. Nor is there any evidence that engineers ever took, as well they might have done, any suggestion from the study of the engineering methods of plants. Similar results have been acquired independently along two quite distinct lines of evolution. In the one the results have followed from human calculation and experiment, in the other they are described as adaptive. But it is still an open question in what degree the mechanical structure seen in plants is related causally to the requirements which it so effectively meets.

CHAPTER XX

TIMBER

MOST country-bred boys know how to make whistles from the twigs of broad-leaved trees in spring time. A length of two or three inches is cut from one of these, about half an inch in diameter. It is then trimmed into shape, and a transverse cut is made in a ring through the superficial tissues near to one end ; if then the stem be gently bruised all round, the tube of outer tissues will easily slip off from the woody cylinder within. The boy little thinks that the surface where the tissue breaks is the cambium, that layer which gives rise to all the timbers of commerce. The reason why it gives way after bruising is that it is delicate, weak, and juicy in the spring, which is the time of its greatest functional activity (Fig. 98). Its thin-walled cells are then growing and dividing repeatedly, and thus it brings into being each year another of those annual rings which mark by their number, as seen in the transverse section, the approximate age of the woody trunk. A sheath of new wood is deposited each season outside that which was already there, and so in the course of years the woody core grows till it becomes marketable timber (Compare Figs. 40, 41, pp. 97, 98).

The specially remarkable feature of this active tissue of the cambium is that it comprises certain cells that retain their youth permanently. These remain thin-walled and densely protoplasmic, and, lying dormant during each winter, they awake to renewed activity
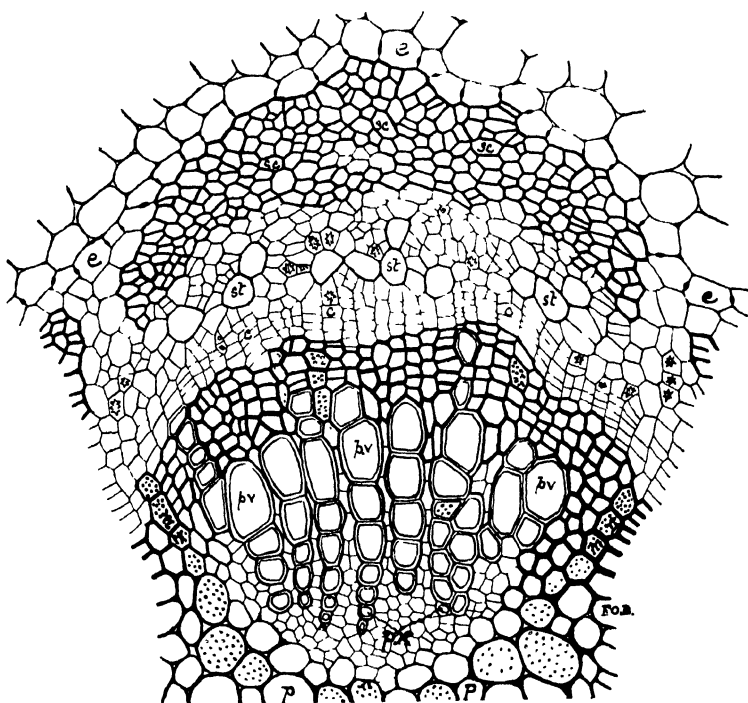
FIG. 98.— TRANSVERSE SECTION OF A VASCULAR STRAND OF THE YOUNG STEM OF THE ELM.   The wood, marked by large pitted vessels (*pr*), is directed downwards, and the bast, with its hard sclerenchyma (*sc*), and its thin-walled sieve-tubes (*st*), directed upwards ; the delicate CAMBIUM, marked by thin-walled cells disposed in radial rows, lies just above (or outside) the wood. (150.)

of growth and division in the spring.   Each cell is elongated and pointed, with the longer axis upright in the stem, so that very little change is necessary to convert the cells thrown off from the inner side of the layer into spindle-shaped wood-fibres (Fig. 99). These and other constituents thus added to the central

column are all closely bound together into the com-
pact and coherent mass of wood. In passing from
the stage of the young cambium the cells enlarge,
their walls become thickened and hardened, and often
the living protoplasm is entirely used up in the pro-
cess, so that when fully matured most of the woody
tissues are no longer
actively alive. On the
other hand, some of
them retain their living
protoplasm, and for a
long time serve for stor-
age purposes. In the
outermost, and therefore
the youngest zones of
the woody trunk this is
specially important, for
it is there that the
material for the new suit
of leaves in spring is
chiefly laid aside as the
autumn comes on.
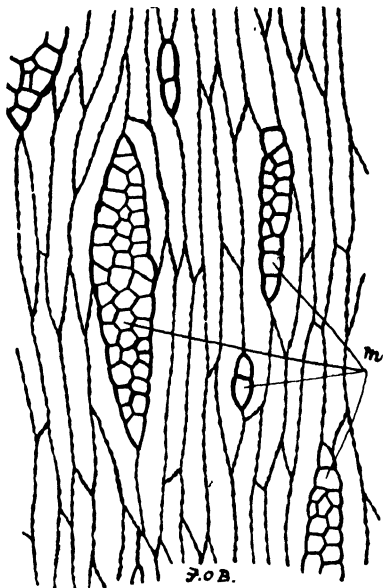
There are two types
of timber in common
use, yielded respectively
by the Pines and Firs

FIG 99.– TANGENTIAL SECTION THROUGH
THE CAMBIUM OF THE ELM, showing the
elongated and pointed form of the prismatic
cambium cells. *M* groups of special cambium
cells that form the medullary rays. (× 100)

(Gymnosperms) and by the broad-leaved trees (Dico-
tyledons). Their wood differs structurally. The
former is the simpler, as one might well expect,
since the Gymnosperms represent an older vegetation,
dating back to the Primary Rocks. The Dicotyledons
have more complicated structure of their wood in ac-
cordance with their more advanced general characters
and their geological history, from which it appears that

the Dicotyledon type emerged during the Secondary Period. The former type includes all " Deals " ; this wood is mostly soft, and in clean trunks is uniform in texture, so that it is easily worked. But the harder Pitch Pine and Yew are also included, while some Gymnospermic timbers are extremely hard. The quality of Gymnospermic woods depends upon the fact that they are built up of one main tissue-type, the fibrous tracheid, a cell-structure which is mechanically resistant, while it also serves as a channel for the transit of water. There is comparatively little storage tissue in this type of wood, and there is the less need for it, since these Gymnospermic trees are mostly evergreen.

Some few broad-leaved trees have also wood of this simple type, and it is interesting to note that this is specially seen in the Winter Green (*Drimys*), one of the Magnolia Family which has a far-back record among the fossils. But most Dicotyledons have their wood composed of three sorts of woody tissue, all derived from cambium cells of the same shape (Fig. 100). They are– vessels (iv., v.) essential for the transmission of water and appearing as tubes, often of considerable width ; storage-cells (iii.), often of cubical or oblong form ; and wood-fibres, (vi., vii.) which are either scattered or grouped in dense masses with their tapering ends interlocked, thus forming a firm mechanically resistant system. The quality of wood as timber largely depends on the proportion of wood-fibres in its constitution. The wood-fibres arise from elongation of the cambium-cells, their pointed ends boring upwards and downwards with sinuous course, so that they interlock, with the result that the greater the strain upon them the more tightly they press upon

one another, and the more compact they become.
This, together with the fact that their walls thicken
so as almost to fill the whole cell-cavity, results in the
masses of wood-fibres being almost the equivalent of
solid strands of resistant woody substance.   Natur-
ally this takes a high polish on working by the joiner
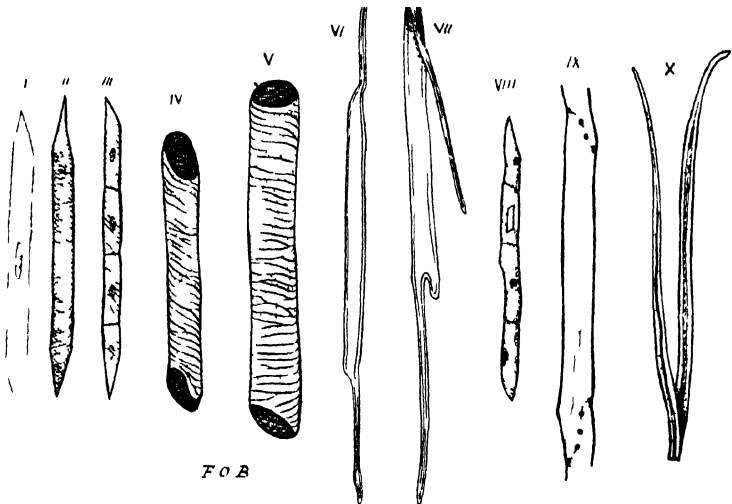
FIG. 100.—THE VARIOUS PRODUCTS OF THE CAMBIUM (c c), which
build up the thickened stem of the Lime. I. is the nucleated cam-
bium cell itself. II. a fibrous tracheid. III. a group of cells of
wood parenchyma. IV. V. single lengths of pitted vessels. VI., VII.
wood fibres bent to save space. VIII. a group of cells of the bast
parenchyma. IX. a single length of a sieve tube. X. a bast fibre
bent to save space in the figure.

or cabinetmaker.   In all the higher grades of cabinet
wood the fibres predominate.
   All the wood of the young stem is at first pale-
coloured, and it is permeated by living cells of the
storage system ; each has its protoplasm active and
able to store the materials acquired during the summer,
or to digest and give them up as required.   But in
many trees, though not in all, as the trunk grows older
the colour and quality of the central wood changes.

It becomes darker in colour and harder, and it is dis-
tinguished as heart-wood.   It is prized by joiners and
cabinetmakers for its strength and durability, and
often for its handsome marking and distinctive colour.
The peripheral zone of younger wood, however, which
is called the sap-wood, remains soft and pale in colour,
and is less durable ; moreover, it is specially liable to
the attacks of vermin, such as the grubs of boring
beetles that make " worm-holes," or by fungi such as
Dry-Rot.   This is due to the fact that the cells of the
sap-wood are still living at the time when the timber
is cut, and will accordingly contain food material that
serves in the dead timber to support such animals and
plants as can feed upon it.   The change from sap-
wood to heart-wood indicates the death of those living
cells.   It is accompanied by the final removal of their
storage contents ; there is a deposit of gums, tannins,
and various other organic compounds which impreg-
nate the cell-walls, while silica and lime also appear
in some heart-woods.   The colouring matters yield
some of the best known dyes, such as that of the Log-
wood tree.   The Tulip tree has a curiously streaky
heart-wood, with zones of pale pink and yellow.

It is not possible here to deal with the detailed
varieties, and specific uses of timber by Man, a topic
in itself vast and intricate.   The immediate point
is the relation of the woody trunk to the life of the
plant.   In this the heart-wood, being dead, takes
no direct part.   Its function is henceforth only
mechanical, and its increased hardness and durability
fit it specially for that purpose.   Apart from this
mechanical support the plant can do quite well
without its core of heart-wood, as is shown by any
hollow tree.   Here the heart-wood has been attacked

by one or another of the Shelf-Fungi, highly
specialised parasites, which are able to digest the
substance of its hardened cell-walls and to work up
the materials into their slab-like fruits (Fig. 101).
Thereby the " nature " is taken out of the heart-
wood, and the resistant tissue is reduced to mere
" touch-wood," which finally breaks down, and the
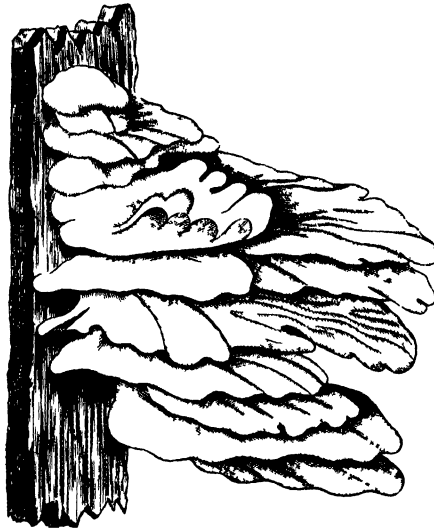
FIG. 101. A PIECE OF OAK BARK BEARING THE FRUCTIFICATION OF
THE SHELF-FUNGUS *Polyporus sulphureus*. The filaments of the
fungus penetrate into the heart wood of the tree and extract from it
the material worked up into the fruit body. (After Marshall Ward.)

trunk becomes hollow. But still the tree may grow
on as though uninjured, for its actively living
sap-wood is still unharmed (Fig. 102).

There are certain other structural features in wood
easily recognised without microscopical examination,
which have their bearing on the well-being of the plant.
When Larch or other coniferous poles have been ex-
posed to the weather, and the bark and bast have
peeled off so as to leave the woody core bare, it is seen
to be marked by gently inclined spiral cracks, which

show that the outer wood itself is spirally constructed. The origin of this is to be found in the fact, long ago noted, that the cambium-cells of the old stem are on the average longer than those of the young stem were ; and the tracheids of the Conifers which are formed from them are on the average longer in the later-
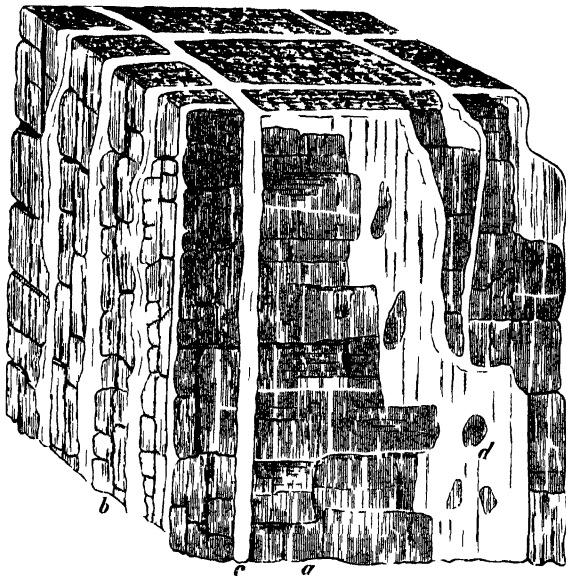
FIG. 102.—A PIECE OF OAK WOOD ATTACKED BY *Polyporus sul phureus*, the yellowish-white mycelium of which is seen at *c* and *d* the wood itself being reduced to touch-wood. (After Hartig from Marshall Ward.)

formed rings than in those of earlier years. If this be so, how else could the longer tracheids be disposed than by assuming this spiral inclination, which is indicated by the cracks ? For it must be remembered that the inner layers of the stem would already be rigid and unable to elongate when the outer are deposited upon them. A like spiral construction is also seen in broad-leaved trees, and even in Cycads. A peculiarly marked example is often seen on the

surface of the stems of the Sweet Chestnut (*Castanea sativa*) as shown by the fissures of the bark. The effect on the stem as a whole will be to give it an increased power of resistance. It would not only be better fitted by the added thickness to bear a dead weight and to withstand the direct stresses of wind, but also to resist more effectively those torsional strains consequent on sudden gusts of wind, or on a lop-sided development of the branches above, which so often appears as the tree grows old. It is interesting to note that this spiral construction in Conifers and broad-leaved trees is matched structurally and mechanically by that spiral course of the vascular strands seen in large Palms, which has been already noted in a previous chapter. But the stems of Palms are developed in quite a different way from those of ordinary timber trees. This suggests that there must be some definite advantage in such spiral construction, where the columnar stem is subject to mechanical strains through exposure to winds.

Another feature which is easily observed in trunks that have lost their bark is the frequent appearance of waviness in the wood, caused by the grain of its outer layers following not straight lines from below upwards, but sinuous lines. It is particularly seen towards the base of a tree, where the leverage would be the greatest, that the wood is disposed in folds running transversely to the axis, like the wrinkles in stockings down at heel. Wood so disposed may be held to form a system of corrugated springs, and it is not improbable that they have a spring-like action in resisting strain on the stem in a high wind. This appearance is again open to explanation as following from an increase in average length of the constituent tissues in the later

layers of the wood, over that of the wood first formed.
It is this that gives the well-known " curl " of the
grain of cabinet woods, such as Mahogany, and in
particular of the carefully selected wood worked up
by violin-makers into that finest of all cabinet con-
struction seen in the instruments of the fiddle family.

The table or " belly " of the violin is made of Pine-
wood with straight grain, and usually very narrow
annual rings ; and it seldom shows any marked curl
of the grain.   Its office is to take up the vibrations
of the strings and to pulsate with them, a duty which
the light and elastic wood of the Pine is specially
fitted to perform.   The back of the instrument is
of some harder wood, usually Plane, but sometimes
Pear or even Beech-wood has been used.   The finest
violins usually show a magnificent curl in the grain,
which arises from the varying angle at which the
sinuous tissues of the carefully selected timber are
cut.   The wood of the finished instrument is made
semi-transparent by the highly refractive varnish
which is thoroughly soaked into its texture before
drying.   The incident light then brings the curl into
prominence, for the sinuous fibres, acting as so many
minute mirrors, reflect the light at various angles, and
this brings the curl clearly into view, varying in its
satin-like sheen with every change of inclination to
the light.   It is quite true that good violins exist
which have featureless backs without any marked
curl of the grain ; but it seems improbable that it is
merely a decorative feature, splendid though it appears
in fine specimens.   Doubtless the wood used by the
great makers for the back and sides was eagerly sought
for and most carefully selected.   The real reason for
this may probably have been partly that the hand-
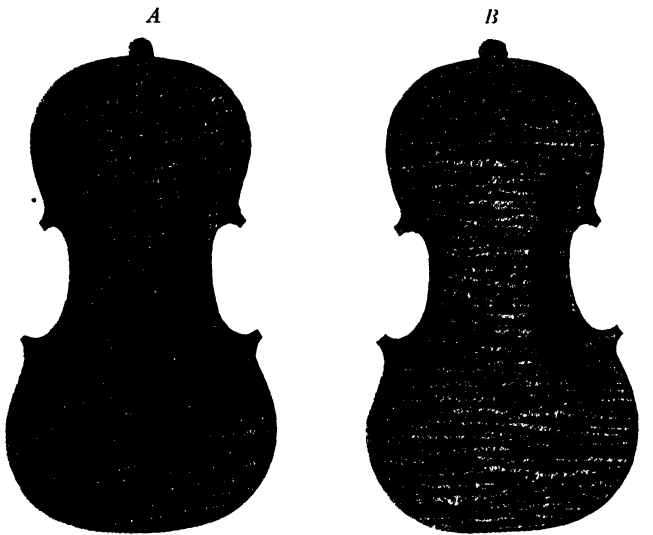
A back in one piece, cut on the quarter, and showing "curl" of the grain.

A back in one piece, cut on the slab, and showing "curl" from a different aspect.

[From "Antonio Stradivari," by kind permission of Messrs. W. E. Hill & Sons, London, W. I.]

FIG. 103.
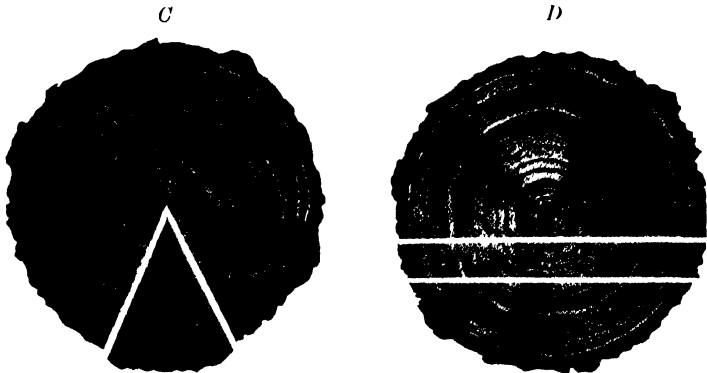
Section of a Tree showing (*C*) the wood cut on the quarter or right way of the grain (radially); (*D*) cut on the slab, *i.e.* across the grain (tangentially).

FIG. 104.

some instruments commanded a better price, and some
good judges hold that this is all.   But may not the
selection have been stimulated by the results of ex-
periment and concentrated observation ?   The makers
may thus have come to realise that the wood which
resisted elastically the strains during growth in the
open forest, would be the very best medium for taking
up and resisting elastically the vibrations conveyed to
it by the sound-post from the belly of the violin, and
ultimately from the vibrating strings.   Whether their
practice was based on intuition or upon experimental
grounds must remain uncertain in the absence of
definite knowledge.   That their method is probably
correct may be concluded from the fact that the earlier
makers of Cremona used Maple locally grown, with
the small close figure characteristic of the instruments
of the Amati family.   But Stradivari is known to
have sought further afield, obtaining his samples with
broader markings of the curl from Croatia, Dalmatia,
and even from Turkey.   It is hardly probable that
he would have done this merely to secure a more
handsome appearance.

It should surely not be beyond the resources of
modern science to put this question of the physical
qualities of wood with varying degrees and width of
curl to the test.   The results, while illuminating the
practice of the old makers, might very well serve as a
guide to those of the present day ;   while they would
also cast a welcome light upon the methods of resis-
tance to strain by the woody trunk.

The general question of the elastic resistance of
vegetable tissues will be deferred till the next
chapter, and it will there be seen how remarkable are
the physical qualities of those fibres upon which the

mechanical stability of plants is chiefly based. Meanwhile we shall realise, as we note the qualities of the timber and the cabinet woods that are put to such various uses by Man, that there is another and indeed a basic interest which they present. For primarily timber is built up as a means of furthering the development of plants to large size. The more perfect its mechanical construction the larger the tree may grow. But, on the other hand, the more nearly will it then approach to that immutable limit of size which is imposed by the principle of similar structures : for at long last the strength of materials only increases as the square of the dimensions, while the weight increases as the cube.

Turning finally to the produce of forests, viz. the timber itself, which is so vastly important to Man at almost every point in his life, the part he uses is the woody column. As cut from the living trunk about 50 per cent. of its weight is water, and there may be living cells containing storage materials distributed through its mass. The amount of those materials and their localisation will vary with the nature of the tree, and the season at which it is cut. Before use it must be " seasoned," that is, air-dried. But as this process takes time it is sometimes hastened by artificial treatment. The effect of seasoning is to diminish the water-content to that usual for organised materials, *i.e.* from 10 per cent. to 15 per cent., while the mass shrinks, and various cracks, or shakes, are apt to appear. At the same time the living cells lose their vitality, though their organic contents may still remain. These food-materials offer a bait to boring-beetles, whose grubs produce the familiar " worm-holes " in their search for food. The outermost layers,

or sap-wood, as we have seen, are specially liable to this ; but so also are certain timbers as a whole, in which storage is general throughout the wood ; such as Beech and Birch. But provided animal and fungal life be excluded, there is nothing inherently the reverse of durable even in such woods, or indeed in timber as a whole. This is shown by the fact that certain piles upon which the Lady Chapel of Winchester Cathedral was built prove as sound to-day as when they were driven by the mediaeval architects. They had been protected from beetles and fungi by being waterlogged throughout the centuries, many feet below the surface of the water-table. Another example of the durability of timber thus preserved was seen in the Oaken piles that supported the Roman bridge at Maintz. It was reported in the newspapers that after their removal from the Rhine they were purchased by a pianoforte manufacturer. It should be realised that what we call "decay" in wood is the result of attack by animals or fungi upon the organic substances composing it, which as food they use for their own physiological purposes. In this respect timber is like the fruit already considered in Chapter XIV. The wooden piles of Winchester Cathedral, or of the Roman bridge, have been for centuries as safely preserved from attack by being constantly submerged, as are the pears we buy from Canada by being bottled. In both the organic mass has been preserved from attack, though the methods of preservation have been different.

CHAPTER XXI

TEXTILES AND TWINE

Textiles and twine play a great part in the life of
Man. Far back in his history the materials for his
clothes and his bowstrings were doubtless supplied to
him by the skins and sinews of animals killed in the
chase, as through the force of circumstances they still
are to the inhabitants of polar lands. But even prim-
itive Man must soon have discovered that the neces-
sary fibres could more easily be secured from many a
plant growing in the forest or the field, and his next
step would naturally be to cultivate them in quantity
round his dwellings. For instance, we know that seeds
of Flax have been found among the Swiss lake-dwell-
ings, and the plant was certainly in early cultivation
among Eastern nations. Though furs and wool still
hold their own for the clothing of Man in cold climates,
linen and cotton have their full share in the markets
of the world ; while cordage is wholly of vegetable
origin, except where it has been supplanted by metal.

So far as the materials for textiles and cordage are
of plant origin, two main sources furnish Man with his
supplies. One is the fibrous cell, developed often in
masses in the plant-body ; its office there is to resist
mechanical strains, and to give stability to an other-

wise soft and pliant structure. The other is the Cotton
cell, developed in tufts or in flocculent tangles that
offer a large surface in proportion to their weight, and
are thus effective in the transfer of fruits or seeds
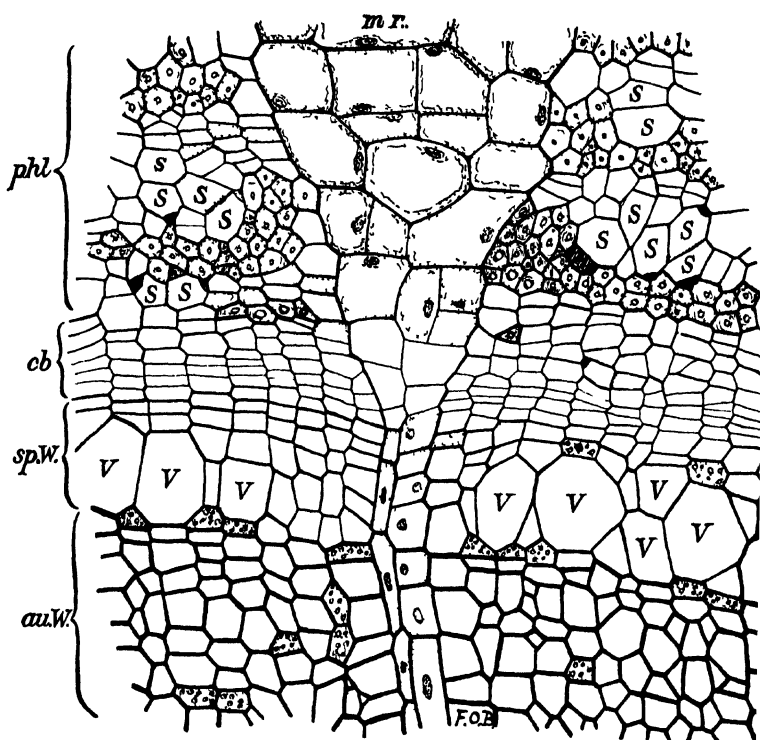
FIG. 105.—STEM OF LIME TREE. It represents the tissues of the
outlined square in Fig. 40, p. 97, magnified 200, it shows the
autumn wood (*au. W*), and spring wood (*sp. W.*) the cambium (*cb*),
and phloem (*phl.*). The thick-walled prismatic cells, disposed in
irregular groups in the phloem, are the BAST FIBRES which when
separated from the rest are used by gardeners for tying up plants.

through the agency of wind (See Fig. 109, p. 253).
The first supplies the raw material worked up into
linen-cloth, sacking, sail-cloth, cables, string, and
sewing-thread; the second yields cotton-cloth, sew-
ing-cotton, cotton-wool, and even such a speciality
as the nap of so-called silk hats. The fibrous cell,

having woody cell-walls, is firm, resistant, and durable ; the cotton-cell, having thin cellulose walls, is pliant, softer, and less durable.

In plants at large the fibrous cell is frequently mixed with other tissues, and built into the vascular system as the wood-fibre, or the bast-fibre (Fig. 105). But there is no necessary association with these, and the strands which the fibres compose lie often quite separate from the conducting tissues. It is such pure fibrous strands that are the most useful to Man for textiles and cordage, while they offer the best opportunity for studying the physical characters of one of the most wonderful products of the organic world. The sinews of the animal body command our interest because of their mechanical effectiveness. Not less should these strands of fibrous plant-tissue receive careful scrutiny. The fibres themselves are long and pointed cells, with their sides flattened so that they fit closely together into a compact strand, while they may also interlace so that when exposed to strain the mutual pressure of one on another consolidates the strand still further (Fig. 106). The individual cells of hemp fibre are about 100 times as long as they are broad ; in flax, which gives the linen fibre, the proportion is about 200 to 1 ; and in the extreme case of the Rhea fibre (*Bœhmeria*), which is a nettle, the length of each cell has been estimated at 1500 times its breadth. The woody walls of the fibrous cells may be so greatly thickened that the cell cavity is obliterated. The strands are thus practically rods of resistant material, and mechanically they act like solid metal wires.

This comparison has been pursued into measurements which bring out the characteristic features of

the resistance offered by strands of plant fibres as contrasted with those of certain metal wires. The
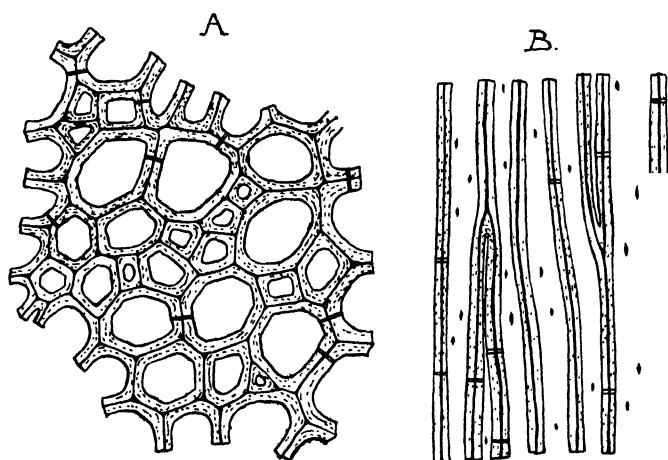
FIG. 106.—*A*, TRANSVERSE SECTION OF A MASS OF SCLEROTIC FIBRES OF THE SUNFLOWER. The thick woody walls are dotted; the smaller sections are of cells cut near their pointed ends, the larger are those cut about the middle. *B*, the same in longitudinal section, showing the pointed ends of the cells; the thick walls are dotted, and the cavities left clear except for a few minute pits. The pointed ends of two fibres are shown. (⨯ 300.)

figures in the subjoined table show how different is the behaviour of the two under strain.

Name.	Limit of Elasticity in Kg. per sq. mm.	Breaking strain in Kg. per sq. mm.	Elongation at limit of Elasticity per 1000 units. of length.
Dasylirion - -	17·8	21·6	13·3
New Zealand flax -	20·0	25·0	13·0
Hyacinth - - -	12·3	16·3	50·0
Garlic - - -	14·7	17·6	38·0
Nolina - - -	25·0		14·5
Silver wire - -	11·0	29·0	——
Wrought iron - -	13·13	40·9	0·67
Steel - - -	24·6	82·0	1·20

The first column gives the maximum burden per unit of transverse section of the fibrous strand or of the

metal wire respectively, under which the limit of elastic recovery is not overstepped. It will be seen that the figure for the fibre of Nolina (25) is actually superior to that for steel (24·6). Other fibres compare favourably with silver and with wrought iron. The second column gives the burden per unit of transverse section which causes rupture : that is, it states the limit of tenacity, or breaking strain. It is seen that here metals are distinctly superior. But the table brings out a very important feature of plant-fibres, which is that their limits of elastic recovery and of tenacity are very nearly the same, while those of metals are widely apart. Put into plain English, the point is that *metals are ductile, but fibres are not.* The importance of this to the plant is obvious ; it lies in the provision that is thus made for perfect recovery after strain. A high figure for the breaking strain would be of no value if after successfully resisting the strain the plant were permanently deformed. Imagine, for instance, a Palm with a straight upright stem exposed to a wind. The fibres on the windward side would be strained. What we see is that when the wind is past, the upright position is accurately resumed. If it were not so there would never be an upright Palm at all. In Nature if every time the stem is strained the plant were permanently deformed it would greatly lessen its efficiency. This explains the importance of the close correspondence of the figures for plant fibres in the first and second columns.

The third column shows the elongation which the strand or wire suffers at the limit of elastic recovery, stated in terms of units of length per 1000 of the strand as a whole. Here the difference between the fibres and the wires is strongly marked, the fibres yielding in much

higher degree than the metal wires.   This again meets
the requirements of a plant exposed to strains, such as
the wind ; for there is no need for the plant to stand
stiffly up ; it loses nothing by yielding temporarily,
provided it can recover perfectly again.   Accordingly,
though metals have the superiority over fibres in tena-
city, the fact that they are more ductile though more
stiffly resistant than fibres would unfit them for fulfilling
the office required of mechanical tissues in the plant.

The general comparison has been drawn in previous
chapters between the mechanical construction of
the parts of the plant-body and that of ferro-
concrete buildings, or the girder-construction so com-
mon in bridges, gasometer frames, and other engi-
neering works.   In the present instance those strands
composed of fibrous cells, the properties of which have
just been described, do for the plant a duty comparable
with that of the metal straps, either of Man's ferro-
concrete or of his girders.   Being themselves resistant
but highly elastic, they are built into the softer tissues
composed mainly of turgescent cells that are also
elastic.   Such a structure though analogous in plan
to the ferro-concrete differs essentially in the fact
that the latter is rigid ;   if its form be materially
changed the concrete would crack.   But in the plant-
body, with its elastic but tenacious fibres embedded
in softer cells, a considerable change of form is per-
missible in yielding to strain without any permanent
injury.   In this the plant has a distinct superiority
over ferro-concrete, for the embedding medium is
itself elastic.   Plant construction is more nearly
matched by the covers of certain motor tyres, in
which a fibrous resistance is coupled with that elas-
ticity which the rubber medium will give.

The comparison with girder-construction is probably closer than that with ferro-concrete.   The strands of
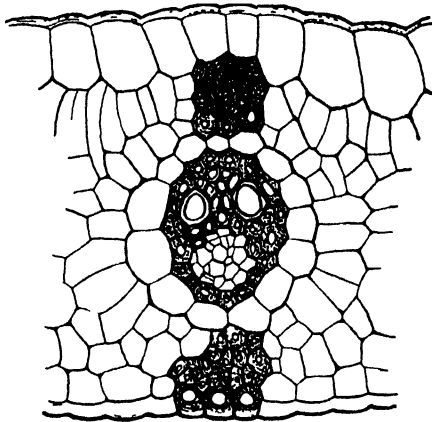
FIG 107 — TRANSVERSE SECTION THROUGH PART OF A LEAF OF Cyperus showing centrally a vascular bundle, with strands of hard fibrous tissue above and below it, thus constituting a girder It is fixed in position by the softer tissues that embed it   (× 300)

fibrous tissue in the plant are commonly found opposite one another, especially in leaf-blades.   They are

held in their position by being embedded in softer tissues, just as the upper and lower straps of girders in a bridge are held by ties, or by being built into the structure they support (Fig. 107).   But again the high degree of yielding to strain, which plant fibres show, gives the girder-construction of the plant a much greater plasticity of form than is seen in any ordinary engineering device.   The softer tissues
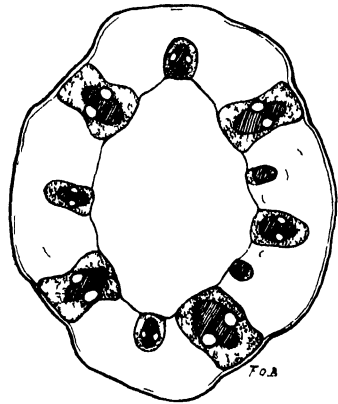
FIG 108 — TRANSVERSE SECTION OF THE SHAFT OF Scirpus (Eleocharis) caspitosa, a Sedge   Four large girders are shown, and four smaller and less perfect ones alternating with them   Centrally is a large cavity   The clear dotted areas indicate thin walled water storage tissue   The structure is comparable to that of a small gasometer frame   (× 62)

yield with the fibrous girder that they embed, and
provided the strain has not been too great the original
form is recovered when the strain is relaxed (Fig. 108).
Any grass-leaf or stem in a wind shows this. The
difference in its behaviour from that of a girder-
construction of steel finds its explanation in that
high degree of elongation under strain shown by
fibres, as seen from the third column of the table
given above.

Strands of fibrous tissue, such as those the nature
of which we have been discussing, were twisted even
by primitive Man into string or cordage. The twisting
reduces the area of transverse section of the whole
rope or cord to a minimum, with the advantage of
spreading the strain equally over all the constituent
fibres, and of allowing them by lateral pressure to
give mutual support. In this spiral arrangement of
the material we see something comparable to the
intimate structure of the individual fibrous cell, for
minute examination of the single cell shows that
there is a spiral structure which may be made visible
in the actual substance of its walls. Space does
not allow a description of the many different fibres
used in cordage or in sacking, sail-cloth or linen-cloth,
their sources or the methods used in their preparation.
The preparation of Flax itself may serve as a general
example. No one who has traversed northern
Ireland in the autumn can have failed to notice the
smell caused by the retting of Flax; butyric
fermentation takes place in the Flax-ponds: the cellu-
lose walls of the softer tissues are thus broken down,
and the resistant bast-fibres are then readily separated
from the softer tissues that embed them. The break-
ing, scutching, and heckling clear the fibre from

impurities, and the strands come out of those processes
arranged in parallel order. Then follow spinning,
weaving, and bleaching, which all go to produce that
finished article, fine linen or cambric. The fibres of
every linen sheet or handkerchief may be traced back-
wards through such processes to their source, and they
are found at last to have been developed as the
mechanical support of the Flax plant. By their means
as it grew it resisted the impact of winds, yielding to
them as they swept over the field, but recovering
perfectly as every gust relaxed
its pressure. No wonder that
vegetable fibres so tested should
supply durable textiles.

Cotton and kindred hairy
growths on the surfaces of seeds
and fruits have never been
subjected to such tests during
their development. They are
of the nature of superficial hairs,
which sometimes grow straight
with a silky sheen, as those borne

FIG 109 —SINGLE SEED OF
THE COTTON PLANT, with tuft of
superficial hairs, which are the
textile cotton   (After Figuier)

on the seeds of the Milk Weed, which have been used
for the nap of " silk " hats. But in the more familiar
Cotton the elongated cells are curled and massed
together within the brittle capsule, expanding as it
bursts so as to offer a large surface to the wind for
distributing the seeds. Cotton is yielded by various
species of *Gossypium*, a genus of the Mallow family. It
has been in use as a textile from prehistoric times in
both the old and new worlds. It was introduced into
Britain in the sixteenth century, but its manufacture
was at first restricted. The manufacture grew to great
proportions in the latter half of the eighteenth century,

and expanded to its present state in harmony with the expansion of maritime trade, since it is itself a product of hot countries, and large markets for the finished article lie overseas.
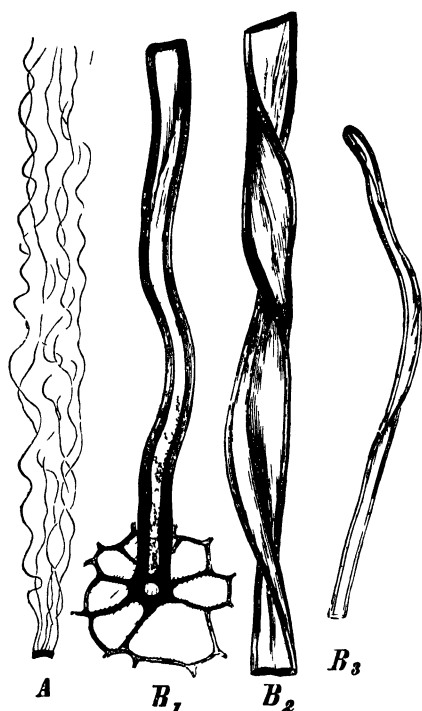
FIG 110   HAIRS BORNE ON THE SURFACE OF THE SEED OF THE COTTON (*Gossypium herbaceum*)   A part of the seed-coat with hairs (× 3) B_1 insertion and lower part B_2 middle part and B —upper part of a hair   (× 300) (From Strasburger)

Single epidermal cells of the seed-coat of the Cotton plant grow out into hairs, often five or six centimetres in length.   They have cellulose walls, and when mature the cells dry up, taking a flattened and often a twisted form.   The flocculent mass of hairs is collected by hand from the bursting fruits, together with the seeds which bear them.   The next step is to separate the seeds by ginning, and the raw cotton itself is then

compressed into bales for export. It is from this
point that the home manufacture begins. It is clear
that such isolated, relatively short and delicate hairs,
with cellulose walls, as those which constitute Cotton
could not compete mechanically with the compact
strands of thick-walled fibres such as linen and jute.
The uses which the two serve in the plants that yield
them stamp their respective characters. Their com-
parison serves only to direct attention more definitely
upon the remarkable characteristics of the fibrous cell.

The extraordinary physical properties possessed by
plant-fibres, which are so vastly useful to Man in his
textile industries, are the very qualities that in a totally
different sphere make possible to him the choicest of
his wooden musical instruments, those of the fiddle
family. In any timber long pointed fibrous cells,
closely fitted together, form a leading constituent
of the mechanical cylinder : and it is from this
that the material is taken for building violins
(See p. 241). Every violinist knows how his instru-
ment awakes with use. After an hour's playing its
tone becomes more smooth and free, which can only
be due to the fibres of the wood taking up more readily
than before the vibrations of the strings. The be-
haviour of strips of wood and metal under repeated
alternating stress was lately made the subject of ex-
periment in the Natural Philosophy Institute of the
University of Glasgow. The specimens were subjected
to repeated torsional and bending stresses continued
over long intervals, the effect of such treatment on the
elastic constants of the materials being investigated
periodically. It was found that the elasticity of wood
of the types used in the construction of stringed
instruments diminished as a consequence of the

treatment specified. The investigation showed, on the other hand, that the elastic properties of metals were increased by subjecting them to repeated alternating stress. This physical property of wood explains the increasing resonance and smoothness of the tone of a violin after use. It also explains the failure of metal. A silver violin was long exposed for sale in a shop window in Soho. The hesitation of purchasers was the natural consequence of the use of a material the physical nature of which would make the tone worse the longer it was played upon. Happily the increased resonance of a wooden violin by use is not permanent, for the fibre regains its power of resistance with rest, and every player has to awaken it again into its best form after it has lain by for a time. Were it otherwise, the older instruments would have long ago become so free and resonant by use that the slightest touch of the bow would bring the tone rushing out in full volume, and it would be more difficult than ever to produce a perfect pianissimo. This last aspect of the fibrous cell relates it to that which is physically the most delicate of the arts, and it shows once more what a wonderful thing this tissue is, which is built into the fabric of the plant for its own mechanical uses.

CHAPTER XXII

PLANT POPULATION AND CONJOINT LIFE

The third chapter of Darwin's *Origin of Species* deals with the numerical increase of living things. Following Malthus, he points out that there is no exception to the rule that every organic being increases at so high a rate that, if not destroyed, the earth would soon be covered by the progeny of a single pair. This fact, stated thus in terms applicable rather to the higher animals, applies equally for plants. Linnaeus, in the eighteenth century, had calculated that if an annual plant produced only two seeds, and their seedlings next year also produced two, and so on, then in twenty years there would be a million plants. But this is the result for annuals only. If the parent is itself perennial, and lives at least twenty years, and if it and each of its progeny produces two seeds every year, and if they all live, the million would be reached at a much earlier term. The production of two seeds in each season is, however, a very slow rate of breeding for plants. Most of them are much more prolific. Thus it has been estimated that a plant of the Common Plantain may produce 14,000 seeds in one season, the Shepherd's Purse 64,000, and the Tobacco 360,000. Darwin calculated that a single capsule of the Orchid,

Maxillaria, contains nearly 2,000,000 seeds. To take an example from nearer home, a large plant of the Common Shield Fern has been estimated to yield about 50,000,000 spores in a season, each being a potential life. Such figures witness to the high fecundity of plants. The brain reels before the figures that might result from a continuance of it through a term of years, if all the possible lives were carried on to the adult state. That this is no fancy picture may be shown by sowing the spores of the Shield Fern under favourable conditions. Almost every one of them will start off in germination, and if the conditions continued good might itself pass to the state of parentage. But Shield Ferns, which may live for twenty years or more, are not becoming commoner than formerly. The woods where we knew them to grow years ago look the same as of old. We must, then, conclude that very few units among those millions annually produced succeed in growing to maturity, and replacing those that met our eye in former years. The losses in wild life are appalling. Such mass-catastrophe throws into relief the ultimate victory won by the few, owing to chance, or to the power of their exuberant vitality in resisting extinction.

On the other hand, under favourable circumstances, it may sometimes be seen how successfully prolific plants may actually be, even where the number of seeds is not specially high. A good example is supplied by the " Marquis " Wheat, which was derived from a single head in 1903, as a result of hybridisation. The " Marquis " strain has since been spread through Canada and the United States. In 1918 it was sown over 20,000,000 acres of land, and yielded some 300,000,000 bushels of grain. So wonderful a result

of breeding from a single parent in a cultivated plant
under control, and in a limited number of years, illus-
trates the actual effect of a geometrical ratio of in-
crease. The same might happen in open nature if
the circumstances were equally favourable. But this
they can rarely be. We may well ask, what becomes
of the rest in ordinary conditions of wild life ?

Evidently the number of germs produced is far in
excess of the losses by death of adults. The immense
margin is in the first place an efficient reserve to meet
all the contingencies of youth, a period when risks are
generally great. Many seeds or spores never reach a
place suitable for germination ; many fall victims to
the predatory attacks of animals as food ; many
young plants are killed off almost at once by cold,
drought, or unseasonable changes. Fungal attack
takes its toll, especially in the seedling state. But
notwithstanding the number and insistence of these
risks, an overplus persists in any surviving species.
This not only keeps the species in being, but provides
for its spread into new stations. Lastly, the large
numbers provide against competition with other races
which naturally follows invasion. These large num-
bers supply also the material for natural selection to
work upon ; and it is the fittest that will be the most
likely to survive. Thus the advantages that follow
from the prolific numbers will be :—(i) Security of
survival of the race ; (ii) its spread to new stations ;
(iii) ability to compete with other races ; and (iv)
ample scope for selection of the best from a variable
progeny. These advantages justify the apparent pro-
fusion of potential germs.

But beyond all this, remarkable results for the evo-
lution of plants in their behaviour towards each other

follow from the high rate of propagation. Over-
crowding of individuals will naturally result from high
propagative capacity wherever the conditions are
reasonably favourable. This will lead to a close
juxtaposition and contact between organisms not
akin. Any meadow or wood shows this for large
objects, but it applies even more forcibly for minute
plants, such as Algae and Fungi, in which the propa-
gation is often on a very high scale. The opportunity
is thus given for the initiation of various conjoint
modes of life. Most people imagine any ordinary
plant they see to be a substantive thing 'that carries
out its various functions of life independently of other
organisms. In particular they would be ready to
conclude from external observation that each indi-
vidual would at least be responsible for its own nutri-
tion. It is, however, becoming more and more clear
that this is the exception rather than the general rule.
Perfervid patriots may be surprised, and even chag-
rined, to learn that such representative plants as the
Oak, the Scots Pine, and the Shamrock are habitually
dependent in some degree upon co-operation with
lower organisms for their supplies. Even the Leek
(supposing this, and not the Daffodil, to be the emblem
of Wales) may be held as suspect, for it is the fact that
some members of the genus Allium have been found
to have formed a nutritional alliance with fungal con-
sorts. The Thistle is, however, as yet above suspicion.
If familiar plants such as these are actual examples of
a conjoint life, or at least suspected of it, the question
will arise, what plants are really independent ?

According to their nutrition we may divide plants
into two categories. The first includes all such plants
as lead a really independent, self-nourishing life—

these are styled Autotrophic. The second includes all such as are in some sense dependent upon others for part, or even for the whole of their nutrition—these are described generally as Heterotrophic, and there may be very great diversity in the way in which this irregular nutrition is carried out. Certain large families appear commonly, and perhaps always, to lead a normal, self-nourishing life ; for instance, the Grasses and the Crucifers. On the other hand, certain families are as commonly or even constantly dependent, showing some irregular form of nutrition : for instance, the Mistletoes, Pea-flowers, Heaths, and Orchids. The first of these are commonly parasites, growing perched upon other Flowering Plants : a phenomenon sufficiently striking to have attracted the notice of the Druids. But in the Pea-flowers there is physiological co-operation with Bacteria, and in the others with filamentous Fungi. Such examples as these do not by any means exhaust the nutritional devices which have been adopted by plants in the general scramble for food in a grossly overpopulated world. The close herding together of organisms, high and low, small and great, all serving their own ends, naturally leads to close contact. This gives an opportunity for some form of conjoint life, which may work out in the most varied ways.

The simplest of all is that which is the most obvious : it is based upon the strenuous race for the light. There being only a given area of land exposed to the sun's rays, if that area be overcrowded there will be competition for access to these rays, and the tallest plants stand to win. But a high stem involves a large expenditure of material for mechanical support. There are two ways in which this difficulty may be met by

a plant more economically than by forming a strong
woody stem of its own, and it will be seen later how
each of them may lead on to actual parasitism.   One
is by adopting a climbing habit.   Sometimes plants
do this by straggling over others, being hitched up to
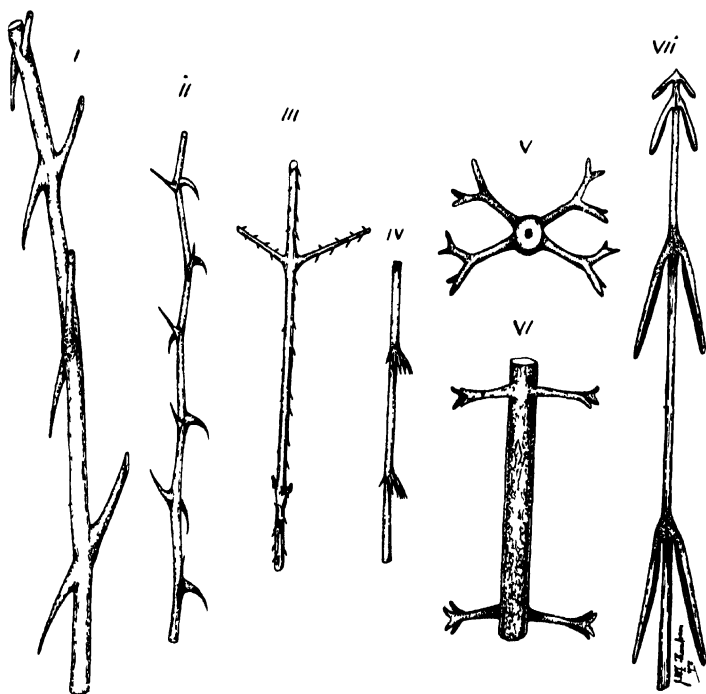
FIG 111 — VARIOUS WOODY STRAGGLERS COLLECTED IN THE
FORESTS IN CEYLON showing various parts of the shoot axillary
buds (i v vi) stipules (ii) prickles (iii iv), or pinnæ (vii) reflexed
so as to give support to the straggling plant that possesses them

them by widely spreading leaves or branches, or even
by reflexed prickles (Fig. 111).   The last may be seen
in any hedge overgrown by the weak-stemmed
Cleavers, or Wild Madder.   Other plants may climb
by prehensile methods, as the Hop or Scarlet Runner,
with·their spirally twining stems; or in the Vine,
Vetch, or Pea, with their clasping tendrils (Fig. 112).

Or, again, the attachment may be by adhesive organs, as in the Ivy with its climbing roots, or the small-leaved Virginia Creeper with its fascinating little self-cementing discs (Fig. 113). In any of these plants, though the stem is weak and thin, the leaves gain access to the light high up. They have saved the materials necessary for forming a firm stem of their own by depending on those of others. But another
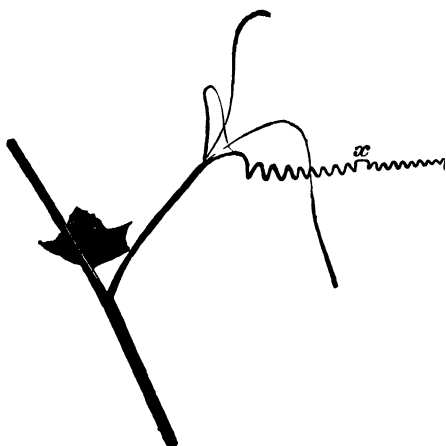
FIG. 112 --PART OF A SHOOT OF A CUCURBITACEOUS PLANT, bearing a tendril by means of which it is attached to a vertical support by lapping round it. (After Strasburger)

way of attaining the same end, though with greater physiological risks, is to dispense altogether with a long stem rooted in the soil, and to start life high up in the branches of a tree, depending upon an intermittent but carefully hoarded water-supply. This is what is called the epiphytic habit, and though it is not largely represented in our home flora, it is a great feature in that stratified or flatted life in tropical forests, which has been described in Chapter VIII, p. 88 (Fig. 34). Our examples have been taken from plants of considerable size, some of them attaining

the highest levels in the forests of the tropics. However, the climbing habit may be seen among humble herbs in temperate regions, as the Vetches clearly show in the hedges, or they may even be seen straggling over the grasses of the meadow.

Close contact of distinct organisms is also established in the soil. This may be noted in the dense mat of roots in any sod, or in the soil of shrubberies and woods. Even the submerged surfaces of water-plants commonly support many smaller plants affixed to them. In particular this has been already remarked for the large marine Tangles, which often bear rich fringes of smaller Algae on their stalks. Lastly, some green Algae and Liverworts habitually grow attached to the surfaces of leaves; sometimes

FIG 113   A CLIMBING SHOOT of *Ampelopsis veitchii*   The ten drils (R) have attached their adhesive discs to the wall surface behind them (After Strasburger)

they even penetrate into surface-hollows, or actually into the ventilating channels of the leaves. There is no need to labour the idea by multiplying examples. It must be clear that a close contact-relation between plants themselves self-nourishing, is a common fact; and the overcrowded life that follows from high fecundity must needs promote it.

It is a comparatively slight step from the state of contact which habitually follows from overcrowding to that closer state of conjoint life where one organism

penetrates the well-nourished tissue of another, and so may gain access to its supplies (Fig. 114). The relation of two distinct organisms thus established may work out in various ways. Theoretically they might live a life of mutual and apparently equal toleration, perhaps even effecting an exchange of materials. But as a rule one gains some distinct advantage over the other. We then call the victim the "host" and the victor its "parasite"—a strange

FIG. 114.—*Loranthus*, a Mistletoe from Ceylon, parasitic externally upon a branch of the Alligator Pear, by means of haustoria penetrating its tissues at intervals. (¼ natural size.)

inversion of the use of these terms as applied in a hostelry. The relation of host and parasite may be one of mutual toleration, though the physiological balance may be unequal, and it may be continued over a long period. But not infrequently the partner which took the initiative causes real damage to the other. It may disturb the function of its nutritive tissue, and so drain it of nourishment that it is dwarfed. It may cause it to develop abnormal swellings ; or it may attack it so severely as to lead to its early death. There may thus be differences in the balance of this conjoint life, which has been styled quite generally " Symbiosis." It may be

defined as physiological partnership, a condition exist-
ing between different organisms.   In some cases there
may be immunity, where, though the two organisms
are in relation, one has no power at all to harm the
other.   In others there may be mortal disease, where
one organism of an association causes the ultimate
death of the other.   In these relations we see the
physiological powers of one organism pitted against
those of another ; and the issue may be tolerant sym-
biotic life, or it may be the actual demise of one
partner ; or some intermediate condition may exist
between the two.

Sometimes external conditions may tip the balance
between organisms, and cause what is called an epi-
demic.   Many years ago a wet and sunless summer
caused a fungal epidemic on White Lilies in the Thames
Valley, so that the flowers failed altogether.   This
climatic effect operated upon both the host and the
attacking Fungus.   The tissues of the Lily developed
thin-walled and watery, being thus ill-fitted to resist.
The fungal spores, produced by well-nourished parents,
were virulent in their attack.   The balance of defence
and attack was thus biased in favour of the parasite,
and an epidemic was the result.   Similar circumstances
precipitated the great potato-famine of Ireland.

The ideas embodied in these paragraphs are of
general biological application.   The invaders last
quoted are minute and highly specialised plants.   But
size is no essential feature in these physiological rela-
tions.   The terms used would be equally applicable
to the Mistletoe, the Dodder, or the Broomrape ; or
on the other hand, to the minute disease-producing
Bacteria.   The action of all these may be held as con-
sequent on the crowding that follows from exuberant

vitality, and high fecundity. We shall examine various forms which this symbiotic life may take, beginning with larger and more familiar examples, and passing to those that are minute. But, as we shall see, a common, though not invariable, consequence is that the invading organism, which obtains its food supply easily, at second hand, ceases to manufacture for itself. It loses its green colour. The photo-synthetic system is reduced, and morphological degradation follows. In the scale of nutrition these dependent plants take their place with the whole animal kingdom, for their life moves in the downward trend of chemical change. This leads towards the restitution to their original inorganic sources of these organic materials won in the first instance by the green plant.

CHAPTER XXIII

PARASITISM IN FLOWERING PLANTS

In human society a brigand is not merely regarded as
a moral delinquent ; he is held to be an enemy of the
State. The foundation for this lies ultimately in Man's
consciousness and volition. It is from his possession
of these powers that the social order which recognises
public and private rights has sprung. In plants there
is no evidence of either consciousness or power of voli-
tion, nor consequently of moral sense. In a crowded
flora there is ruthless competition for any suitable
nourishment that may be available, and the prize
naturally falls to the plant that has the strongest ab-
sorptive powers. Consequently parasitism, or physio-
logical brigandage, may follow at any point where
contact results from overcrowding, provided that one
of the organisms in contact has more power to abstract
nourishment than the other has power to retain it.
Such opportunity is general ; very naturally, there-
fore, the origin of parasitism does not appear to have
been restricted to any definite place or period. Nor
is it restricted to any one group of organisms. It
is true that the most typical instances of the habit
are found among the Fungi, plants probably of
Algal origin, which have existed from very early

times. But many genera of Flowering Plants be-
longing to divers families show it ; and this in itself
suggests that in them the habit has been relatively
recently acquired. Parasitism being thus a pheno-
menon of sporadic origin, it is difficult to speak of it
effectively in general terms. It will be better to study
concrete examples : and for simplicity of description
to choose them first from Flowering Plants.

The Convolvulaceae provide a good instance of the
way in which a climbing habit may lead to full para-
sitism. The common Bind Weed or Convolvulus is a
spiral climber, whose thin whip-like stem twines round
its support, so that its living tissue comes into very
close contact with the outer surface of the host. But
the advantage it derives is merely mechanical ; it is
well able to nourish itself by its large green foliage
leaves, and by supplies of salts brought up from the
soil by the roots. But the genus *Cuscuta*, the Dodder,
which is referred to the Convolvulus family because
its flowers are of that type, comprises plants whose
whip-like stems are almost leafless, and in colour are
sometimes pink, sometimes very pale green or white.
(Fig. 115). Since chlorophyll is almost absent, and
there are no foliage leaves but only a few minute
scales, these plants cannot nourish themselves ;
moreover, the adult plants are not rooted in the soil.
Nevertheless they flower freely in dense clusters, and
produce large well-stored seeds. Examination of the
surface of contact between this root-less climber and
the support that it clasps, will show that numerous
suckers from the former have penetrated the tissue of
the host, so as to establish a series of physiological
bridges between the two. It is believed that these
suckers represent highly specialised roots. Their

position appears to be determined by contact. The method of attack in *Cuscuta europœa* is that first a flat adhesive disc projects from the stem of the
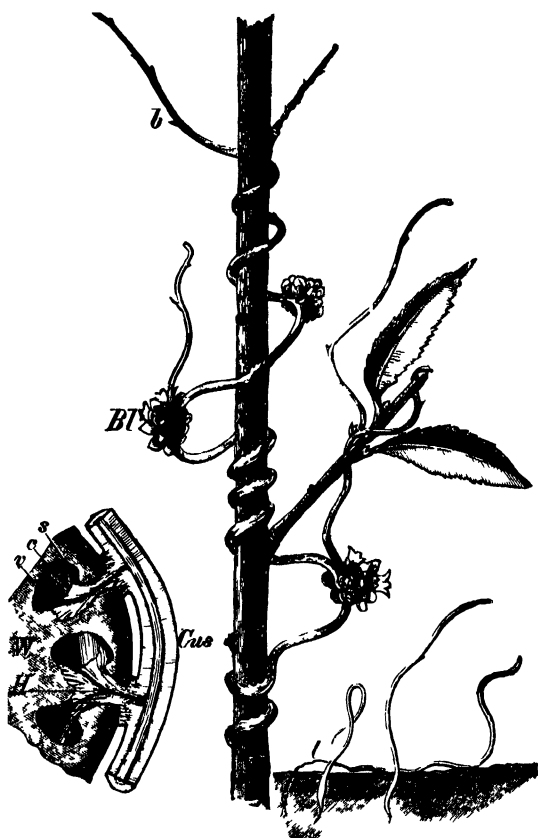
FIG 115 THE DODDER (*Cuscuta europœa*) On the right are germinating seedlings that have not yet found a host In the middle a plant of Dodder twining round a stem of Willow b reduced leaves of the floral region, *Bl* flowers On the left is a cross section of the host showing the suckers of the parasite (*H*) in intimate contact with the vascular strands (After Strasburger)

parasite, attaching itself by broadly spreading hairs to the surface of the host. An active growth from within then bursts through the superficial tissue, just as a young root does, and, like a borer, it

penetrates the tissue of the host, sinking into its tissue softened by a process of digestion. Long rhizoid-like tubes then spread radially out from it, applying themselves especially to the wood and to the pith. Both the conducting tracts and the storage-region are thus tapped, and the parasite is put into intimate relation with the supplies of its victim (Fig. 116). No wonder then that it has need neither
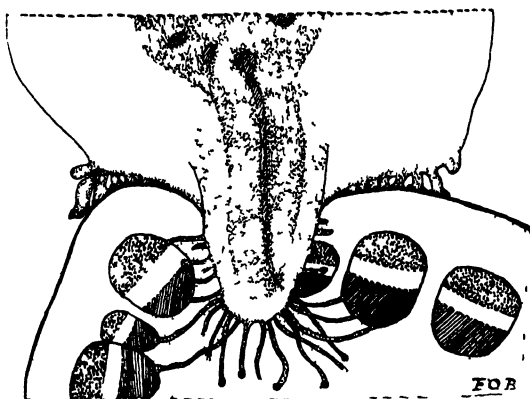
FIG. 116.—SECTION VERTICALLY THROUGH A SUCKER OF THE DODDER showing its penetration into the tissues of the host. For detailed description see Text. (× 3.)

of foliage leaves nor of normal roots. In accordance with the general principle of economy these otherwise essential parts are abortive.

It has been seen that the Dodder seeds profusely ; but how does the seedling of the parasite initiate the attack ? The well-stored seed is able on germination in the soil to start the seedling off in a form suited for success, for its seed-leaves are rudimentary and it produces only a simple tap-root. Almost all the reserve food is used in forming a long whip-like stem, that moves in the air in wide circles, so as to bring about contact with any living shoot within reach. As soon

as this is achieved it promptly becomes a parasitic twiner like the parent (Fig. 115). If the food supply runs out before the contact is made, it dies ; but if contact be made the root dries off, and the plant continues its life in the degraded form shown by the adult. But the degradation is only vegetative; the flowers are normal, though small. The effect of this parasitism on the host is just what one might expect. It may be seen in any Clover field infected by Dodder. The Clover is stunted in growth, but it is not otherwise altered unless the parasite actually smother it. The host does not react by any abnormal growth, such as would alter the external form, though this happens in some cases of parasitism : nor is it poisoned as a whole ; it is merely starved.

Though the adult Dodder is thus isolated from the soil, it starts its germination in the ordinary way. But the Evergreen Mistletoe is an epiphyte from the first, and germinates where it grows, attached to the branches of trees. The viscid white berries, which are one of the sources of bird-lime, are greedily eaten by birds, which wipe their bills on the branches on which they perch to rid them of the sticky seeds. The seeds stick to the twigs, and are thus widely sown. The green embryo, on germinating, protrudes its root, which, turning from the light, forms first an attachment disc, from the centre of which a root plunges into the tissue of the host. It passes to the level of the cambium, and there establishes with the wood a close relation, which is permanently retained. Other roots arising from it run horizontally through the cortex, and they may give rise to fresh shoots, often at a considerable distance from the main shoot. This, which springs direct from the plumule of the seedling,

develops a forking habit, the pale green stem bearing the well-known pairs of yellowish leathery leaves and spikes of minute greenish flowers and ultimately the white berries (Fig. 117).

The remarkable habit thus seen in the Mistletoe, so unusual in temperate countries, though familiar enough in the tropics, naturally drew the attention of

FIG. 117 — LOWER PORTION OF THE STEM (*a*) OF THE MISTLETOE (*Viscum album*) *h* the wood of the shoot axis *i* primary root *ff* roots growing in the cortex of the host branch (*c*) *g* two buds arising from them *ee* so called *haustoria* roots which penetrate through the cambium into the young wood and become surrounded by it later *bb* wood of the host branch cut half across it *dd* showing the annual rings (Natural size, after Sachs.)

primitive races.   The plant has supplied the name of *The Golden Bough* for Sir James Frazer's monumental work.   The green of its shoot, though pale and golden, proves its ability for self-nourishment by photo-synthesis.   But for water and a supply of the necessary salts, it is dependent upon tapping the transpiration stream carried by the wood of the host.   This is secured at once on germination, and it is maintained throughout life.   An absorption of organic food also

is by no means excluded ; possibly the plant does not depend wholly upon the activity of the imperfectly developed pigment. Mistletoe stands thus in an intermediate position as a green parasite which has not dispensed with its own powers of self-nutrition.

The Mistletoe belongs to a widespread family of parasites to which the voracious genus *Loranthus* gives its name. Sometimes species of *Loranthus* seem to contribute fully half of the foliage visible on the trees that it infests. In some species the parasite spreads over its victim by elongated external shoots following the length of the branches, and penetrating by suckers at intervals into the living tissues —a mode of attack more impressive though less insidious than that of the Mistletoe with its internal burrowings (Fig. 114, p. 265). The effect of all such parasitism is to weaken the host-plant. Notwithstanding that large quantities of Mistletoe are forwarded yearly from the orchards of Herefordshire to London as Christmas decorations, the parasite still infests the Apple trees of the cider country to the detriment of the crop.

Another quite distinct family of Flowering Plants is addicted to root-parasitism, which has clearly taken its origin from the contact of roots matted in the soil. While the majority of the Snapdragons lead an ordinary independent life, the group of genera that centre round the Eyebright (*Euphrasia*) present above ground pale and livid colouring of the green shoot, and this goes along with the fact that their roots fix themselves by suckers essentially similar to those of the Dodder upon the roots of other plants, such as Grasses and Clovers. They are, in fact, root-parasites (Fig. 118). The Yellow Rattle is perhaps the most injurious, and its effect on the meadow can be easily noted

from a distance by the stunted appearance of the
crop where the parasite is present in quantity.   The
plants of this family, the Snapdragons, show a very
interesting progression towards complete parasitism
and the loss of the chlorophyll-function altogether.
Starting with the fully self-nourishing types, such
as the Mullein and Foxglove, there is nothing to
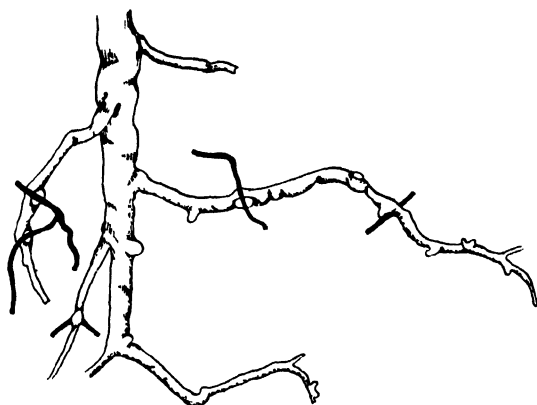
Fig. 118.— Root-System of the Louse-wort (*Pedicularis*),
which, like Eyebright and Yellow Rattle, fixes itself by suckers
upon the roots of its host, fragments of the roots of which are here
represented black.   (After Maybrook.)

remark beyond the fact that they represent a family
with rather advanced floral characters.   But the
Eyebright, Bartsia, Cow-wheat, Louse-wort, and the
Yellow Rattle are root-parasites with a pale or livid
aspect of their vegetative shoots.   Finally, the Tooth-
Wort (*Lathraea*) is a full parasite, with its scaly and
branched shoot blanched underground, and attached
to the roots of the Hazel.   It raises its white
flowering shoots in spring, bearing purplish flowers
of structure like those of the other genera, each
maturing a capsule containing very numerous seeds.
This plant has become wholly dependent for its
nutrition upon its host, and the large seed-output

may be held to be an offset against the initial risks in
establishing so precarious a source of food; though,
when once connection with the host is made, the sup-
ply is ample for supporting many flowers, and nour-
ishing a large number of seeds. It is only a slight
step further to the parasitic family of the Broom-rapes,
which are root-parasites of rather gross habit and
brown colour (Fig. 33, p. 79). The shoot is here
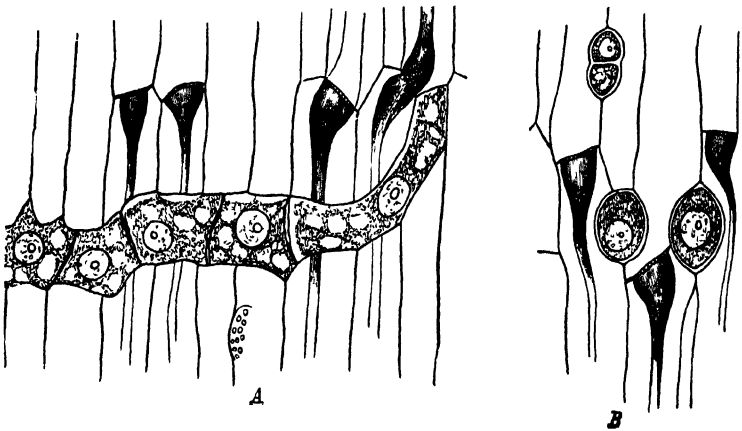
FIG. 119.—SUCTORIAL FILAMENTS OF *Rafflesia* traversing the
secondary bast of a root of *Cissus*, and coming into intimate relation
with the conducting sieve-tubes and the companion cells. *A*, in
radial section through the root, *B* in tangential section. The cells of
the parasite show dense protoplasm with nuclei. (After Haberlandt.)

more modified than in the Tooth-Wort. It forms on
germination a leafless tuberous body; this is attached
by a broad sucker to the vascular system of the root
of the host, which it often exceeds in stature and
usually in bulk. The flowering shoot rises high above
ground, and again we see large flowers with a profuse
production of seeds.

Examples of still further reduction of the vegetative
system, accompanied by flowers some of which are the
largest in the vegetable kingdom, are seen in the fully

parasitic family of the Rafflesiaceae, and these may be held to mark an acme of the parasitic habit in Flowering Plants. It includes genera and species which share a most remarkable character, for the vegetative system is completely enclosed within the tissues of the host. A small form, *Pilostyles*, which grows on various Mimoseae, has been fully examined, and the vegetative system of the parasite has been found to consist of fine filaments like fungal threads which perforate the cells of the host, and traverse its conducting column (Fig. 119). The attack is exactly along the same lines as that of a parasitic Fungus. But the proof that this greatly reduced body is really a Flowering Plant appears when it forms buds that burst through the skin of the host-plant, as flower-buds. Though these have a curiously specialised structure, their features are unmistakably those of a Flowering Plant (Fig. 120).

To the same family, to which the genus gives its name, belongs that most wonderful object, *Rafflesia*, first discovered on the island of Sumatra by Dr. Arnold. Its flowers are " a full yard across," of a livid red colour ; they smell like carrion, and are pollinated by carrion-flies. This is again the flower of a parasite. Its vegetative system develops within the tissues of the root of a Vine, and is, like that of *Pilostyles*, of a degraded type. The flower-buds borne upon it burst through the tissues of the host, appearing like Drum-head Cabbages (Fig. 121). The flower itself is not only large, but also complex in its structure, and the seed production is prodigious (Fig. 122). Biologically, the large number of the seeds may be held as an offset to the risk of their not finding the proper host on germination.

A general parallel may be drawn between such parasitism in plants and that in animals. The general similarity of the effect of the habit upon organisms so

Fig 120 —Branch of a Leguminous Plant from the surface of which the flowers of the parasitic plant *Pilostyles* are projecting, while the suctorial system is enclosed within the tissues of the host (After Goebel, from Strasburger)

diverse as *Rafflesia* and a Tape-Worm or a Liver-Fluke may be held as demonstrating the biological principles that underlie it in either kingdom. In both the phenomenon is sporadic, a fact which indicates that it arises in relation to opportunity rather than by any definite

evolutionary trend.   Parasitism brings with it the
easy acquirement of food without the obligation of
gathering or acquiring it by individual exertion.   So
far it is a direct advantage to the organism that
adopts it.   But the habit brings also two natural
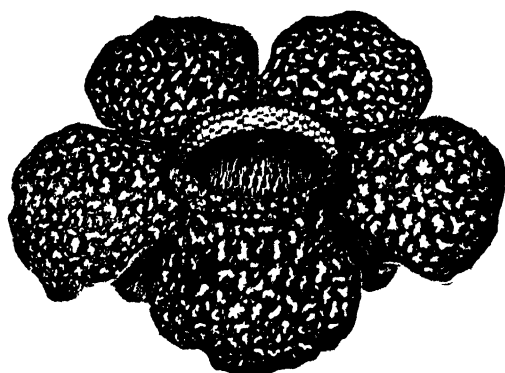
IIG 121   IIG 122

ILLUSTRATIONS OF THE PARASITE *Rafflesia*   To the left a length of
root of the host *Cissus* showing flower buds bursting their way
outwards   To the right an open flower of *Rafflesia* (after Robert
Brown   much reduced)

consequences.   The first is a reduction or even abortion
of parts.   The disused organs –and in particular the
leaves and roots of plant-parasites—not being neces-
sary, are partially or wholly aborted ; while in Flower-
ing Plants developed as parasites the whole vegetative
system may in extreme cases be represented by filaments
no more elaborate than are the filaments of a Fungus
(Fig. 119).   The second consequence is an enormous

production of seeds. Any parasite that has wholly
desisted from self-nourishment stakes all its chances
of existence upon finding the peculiar conditions of its
supply. The chances of its doing so are the more
remote the more peculiar they are. The germs of a
parasite that is successful only on one host must find
that host or perish. The risk of not doing so is met
by the immense output of seeds, which is specially
marked where the parasitism is of an advanced type.
It is seen in the large seed-output of the Tooth-Wort,
which is parasitic on Hazel roots, or of *Rafflesia* para-
sitic on those of certain Vines. If we turn from such
examples to animal parasites, we shall see in the Liver-
Fluke and in the Tape-Worm conditions of simplified
or indeed degraded bodily structure, and of high
fecundity, which may be read as similar responses to
biological conditions that rule for parasitism in either
kingdom. They provide indeed some of the widest
possible examples of homoplasy : that is, the similar
reaction of unrelated organisms to like conditions of
life. It appears, then, that the result of parasitism
may be stated quite generally for any living type,
including even Man himself : once the individual
reaches maturity, physiological dependence and
degradation tend to go hand in hand.

CHAPTER XXIV

MYCORHIZA

THE title of this chapter will probably be unfamiliar
to most readers. But let them not turn away from
the strange topic on that account, for it embodies a
most interesting phenomenon of plant life, and one
which is much more common than is generally per-
ceived. Its discovery was comparatively recent, and
such facts as will now be described had hardly been
imagined some forty years ago. The name is used to
connote a relation established between fungal filaments
and the roots of certain larger plants. The Fungus
and the root grow together in varying degrees of
mutual accord, and the relation between them is one
of the best instances of what is called Symbiosis, that
is, physiological partnership, or conjoint life. Darwin
is reported to have said that he loved plants because
they present the phenomena of life in their simplest
form. We shall see that this applies for Mycorhiza,
which presents the mutual relation between an in-
vaded and an invading organism on such a scale that
it could be readily studied, and the results compared
with those that follow where the invading organism
may be a minute bacterium, and the invaded organism
perhaps the human subject itself. In point of fact,

the study of Mycorhiza will illustrate various degrees
of mutualism.   But here the tissue invaded is that of
a plant, not of an animal, and it is this which makes
the observations in certain respects easy.

In a previous chapter it has been noted that many
plants which look as though they were normally nour-
ished are not really independent, but are liable to form
a physiological alliance with fungal consorts.   Since
their roots are the parts chiefly affected, nothing
peculiar may be visible above ground.   Trees such as the
Beech, Hornbeam, Oak, or Scots Pine are examples of
such fungal alliance.   In certain families the alliance
is prevalent, and has even become a necessary condi-
tion of life, as it is in some of the Heaths and Orchids ;
while similar fungal alliances are found in Club Mosses
and the Adder's Tongue Ferns, and it occurs also in
some Liver-Worts.   Thus it is not restricted to any
single family or group of plants.   This alliance is de-
scribed as " Mycorhiza," and it consists in an intimate
relation between the filaments of certain Fungi com-
monly present in a humus soil and the living tissues
of another plant.   If the fine rootlets of trees such as
those named be dug up from rich vegetable mould,
many of them will be found to be thick and fleshy.
very frequently branched, and brittle in fracture
(Fig. 123).   A microscopic examination reveals the
fact that there are fungal filaments in close com-
merce with the living tissue of those roots.   The
essential and surprising fact is that the affected tissues
remain actively alive, and it is to this living coalition
that the name is given.   It does not necessarily exist,
however, on all the roots of a plant ; some root-fibres
may appear normal, especially where they traverse
poorer soil.   This fact suggested at first that the

coalition might be a casual circumstance of no real
physiological importance. But it has been shown
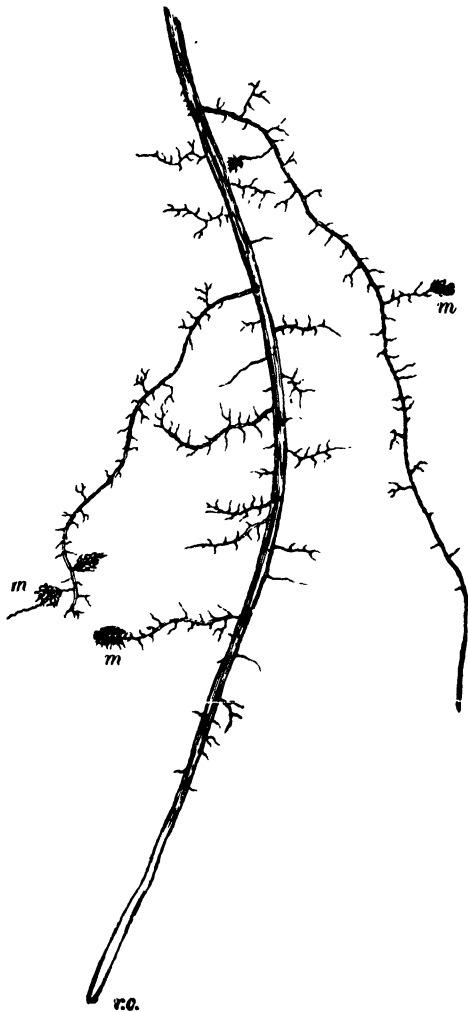
Fig. 123.—Portion of a Young Growing Root of the Oak
with numerous rootlets. Some of the latter are much branched into
tuft-like masses (*m*). These are the mycorhizic parts. (Natural
size. After Marshall Ward.)

experimentally that the association with the fungus is
beneficial, by growing young plants, for instance of

Beech and Pine, in pots filled with rich forest soil.
Some of these pots had been sterilised at 100 degrees
C. to kill the Fungus ; in others the soil was normal.
The plants in the latter formed Mycorhiza, and throve ;
those in the sterilised soil formed no Mycorhiza, and
grew feebly. Such evidence shows that the coalition
is useful. The fact is that Fungi have special powers
of absorption of certain substances from the medium
in which they grow. They expose a large absorptive
surface and readily extract soluble salts from the soil.
They are also able, in accordance with their mode of
life, to draw organic material in the combined form
from rich humus. It is powers such as these that
make a coalition with them a physiological advantage
to ordinary green plants, and, as we shall see, Mycor-
hiza may even lead indirectly to a state where green
chlorophyll is dispensed with altogether, the plant
assuming a pale colour. This would be recognised as
complete saprophytic nutrition, that is, dependence
wholly upon absorption of dead organic matter.

Two different types of the mycorhizic state are
recognised. In the first the Fungus lives outside the
tissues of the plant with which it is related. This may
be described as external, and it occurs in the Beech,
Hornbeam, Oak, and Scots Pine ; also in certain
pale saprophytes, such as *Monotropa* and *Sarcodes*
(Fig. 124). In the second the Fungus penetrates the
tissues, and it may accordingly be styled internal; it
occurs in the Heaths and Orchids, and in other pale
saprophytes, such as the Bird's Nest Orchis. Thus
both types may culminate in full saprophytic life,
where nutriment is wholly derived from dead and
decaying organic matter.
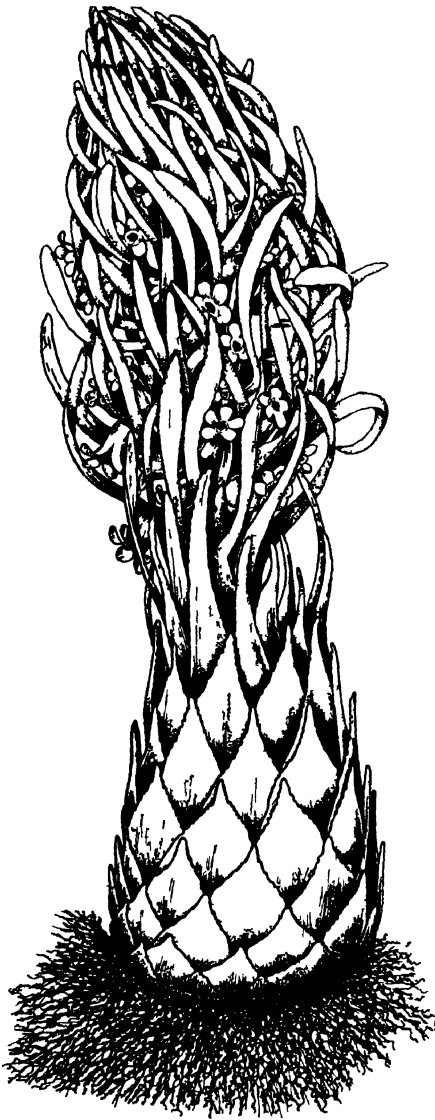
EXTERNAL MYCORHIZA

Roots showing external Mycorhiza appear entirely enwrapped by a thick felt of matted fungal threads, which may even extend over the root-tip, so that it does not come into direct contact with the soil at all. The filaments may make their way between the superficial cells, but do not as a rule penetrate them.   On
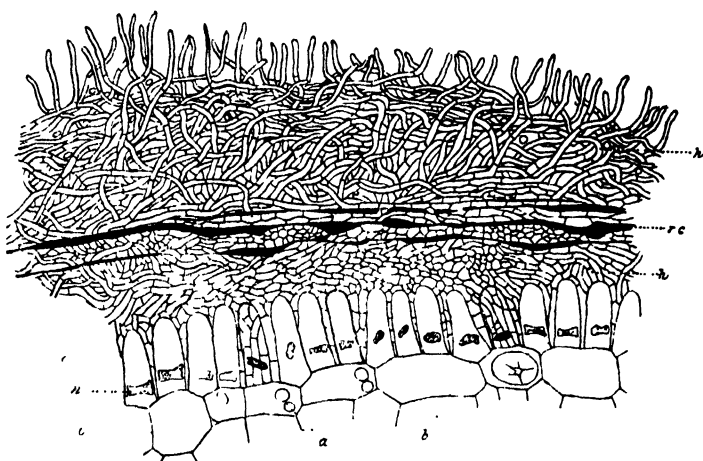
FIG. 125 —PART OF THE SUPERFICIAL TISSUE OF A ROOT OF *Sarcodes* covered by a dense felt of fungal hyphae (*h*), in which the dark lines (*r. c*) are layers of the root-cap   The outermost layer of cells of the cortex (*c*) is covered by a piliferous layer (*r*), but the root-hairs are replaced by conical cells between which the fungal hyphae have forced their way.   (After Oliver)

the other hand, many filaments grow into absorptive threads that penetrate the soil and take the place of the root-hairs, which as a rule are not formed in such roots.   In fact, the Fungus makes itself a sort of physiological middle-man, and the root receives all that it derives from the soil through its agency at second hand.   Where, as in *Monotropa* and *Sarcodes* (Fig. 124), the plant is pale and without chlorophyll, it must receive the whole of its nutritive supplies from the soil

through the medium of the Fungus. In estimating the mutual relations of the two parties to external Mycorhiza in green plants, such as Oak or Pine, the state appears to be permissive rather than necessary. On the side of the Fungus a direct supply of carbohydrate may be obtained by contact from the root, and this would give an initial advantage to it. The advantage which the tree derives is, firstly, a more ready supply of salts and of combined nitrogen extracted together with water from the soil by the Fungus. But, further, the Fungus establishes a more intimate relation with the soil than root-hairs usually do, and there is abundant evidence of their power of extracting organic materials from a rich humus. These also may be handed on to the root. That the relation is mutually satisfactory is shown to be probable by its prevalence and by the vitality which characterises both parties.

The importance of this form of nutrition varies greatly for different plants. It culminates where the plant itself is almost or entirely without chlorophyll of its own, as in *Sarcodes*. Here not only water and salts, but even all organic supplies, are obtained through the Fungus from the humus substratum. It may not perhaps be strictly true to call these plants themselves saprophytes, or feeders on decay ; but the legal maxim runs, " qui facit per alium facit per se." These colourless plants are physiological resetters, or receivers of stolen goods. They are saprophytes at second hand, being actually parasitic on a saprophytic Fungus. It is quite possible that the same may be the fact even for the Beech, Oak, or Scots Pine, though in a less complete form.

Internal Mycorhiza

The two types of Mycorhiza are not absolutely distinct from one another. Occasionally the external Fungus in *Monotropa* or *Sarcodes* is found to penetrate the superficial cells of the host, which suggests how the more prevalent internal Mycorhiza may have arisen. This form of coalition between a higher plant and a Fungus is very much more interesting than external Mycorhiza, owing to the circumstance that the fungal filaments habitually occupy the living cells of the host, coming into intimate relation with the living protoplasm. The filaments inside may, however, be still connected with the soil outside by threads passing sometimes through the superficial hairs of the host. Usually the cells that take part in this co-operation are restricted to certain zones, and especially to the region of the cortex. The filaments appear coiled within each cell, while the protoplast and the nucleus of the host-cell still retain their vitality. In fact a mutual life is maintained : a condition of intimate symbiosis.

The internal Mycorhiza is characteristic for Orchids and Heaths, and for various other plants. There is great variety in the colouring of the hosts of this type. Most of them are full green, as in *Rhododendron*, and Heather : they look in fact like normal plants. Some are pale in colour, as the Orchids *Goodyera*, or *Listera cordata* ; others may have no chlorophyll at all, and be brownish, like the Bird's Nest Orchis. These differences suggest varying degrees of dependence upon some other source of food than photo-synthesis. For an explanation we shall look to the Fungus, and examine the alliance in detail in such well-known

plants as the common Heather and the Bird's Nest Orchis. In the Heather the Fungus has been found not only in the root, but in the stem and leaves, and it extends to the flower, and even to the coats of the seed; but the germ itself is free from it. Shortly after germination, however, the seedling is infected from the seed-coat. It has been shown by pure sterile cultures that without this infection the seedlings do not form roots, and their growth stops. But on infection with the right Fungus they develop normally. The synthesis, or bringing together of the two so as to
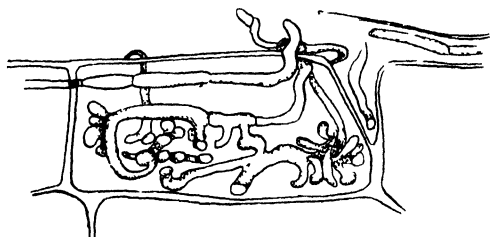
FIG 126 —A SINGLE SUPERFICIAL CELL OF THE YOUNG ROOT OF COMMON HEATHER (*Calluna vulgaris*) showing the endotrophic Fungus, and its penetration of the cell walls The protoplast of the cell is omitted (After Rayner) (× 500)

establish the Mycorhizic state, has been actually carried out with success. The conclusion from such experiments is that the common Heather cannot now carry out its normal life without the co-operation of the Fungus, and a similar state holds also for others of the Heath family. The Fungus resides chiefly in the outer cortex of the hairless root, where the filaments grow between the cells and even penetrate their walls, while the protoplast and nucleus of the Heather-cell may still retain their vitality (Fig. 126). On the other hand, the filaments also extend outwards into the rich humus soil in which the Heather grows, and would thus be able to act as middle-man between

the plant and the soil: In the stem and leaf the
Fungus is found among the superficial hairs, but
also within the tissues, following the course of
the vascular strands. Possibly it may be able to
fix atmospheric nitrogen in some degree, in addition
to collecting combined nitrogen from the soil. In
any case the mechanism at least is here present for
the Fungus to act as a physiological intermediary
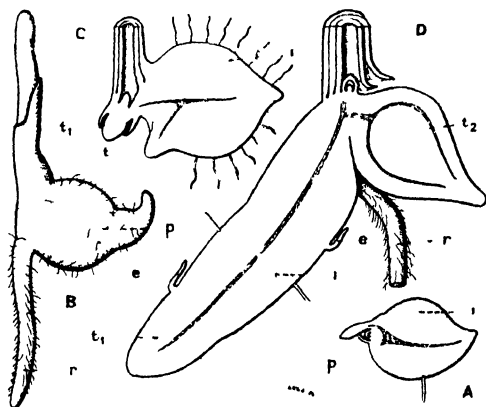
FIG 127 YOUNG SEEDLINGS OF THE OPHRYDEAE SHOWING
MYCORHIZIC TUBERS A young tuber of Orchis in section B young
plant C young plant of Ophrys in section D diagram of
young plant of Platanthera seco 1 year, p tuber of first year
t t succeeding tubers e sec s r infected region r root
(After Bernard)

between the Heather and its surroundings, and it has
been shown to be indispensable to its normal life. By
means of this symbiosis many of the Heath family have
solved the problem of growth on poor and unpromising
soils, but they have solved it at the price of their
independence.

A similar relation has been shown to exist in the
Orchids, and it may be held as a general feature of this
family. The filaments of the Fungus live in the cells
of the host, forming dense coils embedded in the living
protoplasts. But they are restricted to certain definite

regions, being prevalent in the cortex of the roots. They never penetrate to the young embryonic tissues of the apical region. In fact, though they are able to pass from cell to cell, and so to permeate considerable tracts of tissue, the host keeps the Fungus in check, restricted within more or less definite limits. Branch filaments, however, pass outwards through the root-hairs. There is no doubt of the benefit which follows from the joint-life ; it has been shown by cultures of various Orchids that the infection happens early, sometimes at once on germination, while the presence of the Fungus appears to be necessary for the formation of those tuberous swellings so characteristic of our own native Orchids (Fig. 127).

The physiological story is clearest in the colourless types which have become fully saprophytic, such as
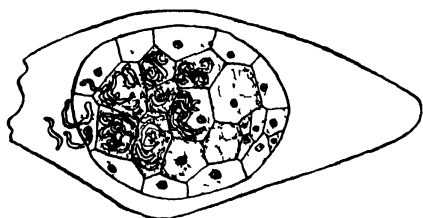
Fig. 128. Seed of *Neottia* already infected by the Mycorhizic Fungus, and showing the first stages of germination. (After Bernard.) (100)

the Bird's Nest Orchis. Here the infection is already established in the earliest stages of germination (Fig. 128). The short rhizome bears those crowded fleshy roots that form the so-called " bird's nest " underground. The nourishment of this strange body which supports in early summer the brown spike of flowers is wholly saprophytic, through the medium of the Fungus. The filaments of the Fungus are restricted to certain layers of the middle cortex of the roots, but

they communicate with the soil by outward-growing
filaments. After a period of active development
digestion of the filaments by the host takes place in
certain cells whose nuclei grow and become lobed in
form (Fig. 129). Finally, only indigestible fragments
of the fungal filaments remain, while starch appears
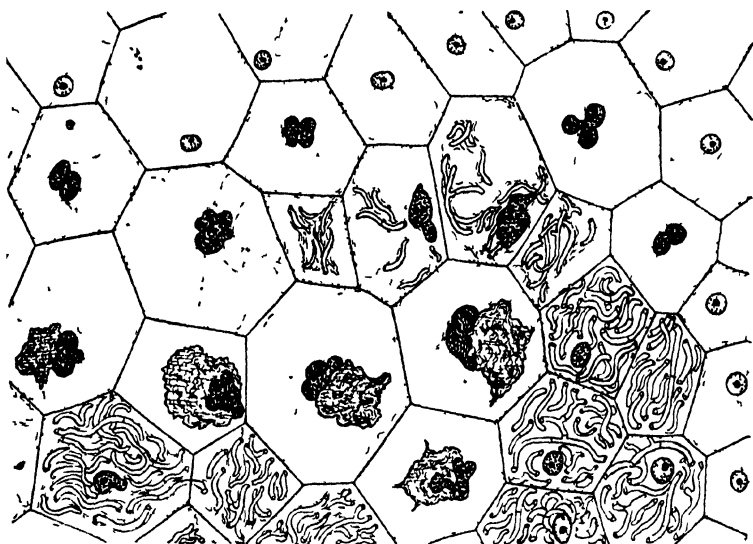
FIG. 129   SECTION THROUGH THE MYCORRHIZIC REGION OF THE TUBER
of *Phalaenopsis*   At the top of the figure are normal cells of the host
at its lower limit are cells crowded with fungal filaments but still
retaining their nuclei   Between these zones is the digestive tract
consisting of cells with lobed nuclei   Various stages of digestion of
the fungal filaments are seen in these cells   (After Bernard) (18)

in quantity in the adjoining cells of the cortex as a
witness of what the host has gained by the whole
transaction.

Such symbiotic conditions as these described for the
Heaths and Orchids occupy a middle position between
the extremes of immunity on one hand and mortal
disease on the other. An intermediate state of this
sort is realised in nature when two organisms, by
balancing their powers, attain to a life of mutual

toleration. This stage may last for a prolonged period, as in the mycorhizic plants. But the period of toleration may at any time be ended by the host putting forth increased powers of digestion, which curtail the activity of the invader, or even annihilate it. The parallel between this behaviour as seen in the Orchids, and that of the Leguminosae with their bacterial tubercles, is striking. In both cases the host rounds upon and digests the temporarily permitted guest, using the food so acquired for its own purposes. Such host-plants may be styled " fungivorous " in a sense parallel to the " carnivorous " habit acquired by some plants. A near parallel is further to be found in the digestion seen within the single cell of the *Amoeba* ; or, going a step further, these happenings are all of the same order as the action of the " phagocytes " existing in the human blood : for they are cells which clear off intrusive germs by digesting them.

It is thus seen how interesting are these coalitions of Fungi with the higher plants, which are included under the heading of Mycorhiza. Not only may we recognise in them many examples of mutual life existent in representative, and even in common plants; but they also provide comparisons with what has become familiar in the animal body, viz., various degrees of mutualism extending between the extremes of mutual toleration and mortal disease. Severe control of an invading organism may appear as an intermediate state. This is seen in the plant-body in that power which mycorhizic plants possess of controlling the spread of the Fungus, and heading it off from the essential tissues of the apical point, and often from the conducting tracts. But finally it may be digested bodily, in a manner analogous to phagocytosis, as seen

in the animal body, or even in Man himself. These happenings may all be referred to the relative physiological powers of the two organisms involved. The powers of attack and of defence may be expressed in terms of those digestive ferments which the protoplasts of invader and of host are respectively able to secrete. If that of the Fungus is sufficiently powerful, invasion may take place ; if the power of the host is strong enough, the invader may be arrested or even overwhelmed. But middle positions are possible in various degrees, and these exist as mutualisms. Such is the state of Mycorhiza, so long as the invader and the host act in harmony together. If, on the other hand, the Fungus is unable to penetrate the potential host, the latter would be described as immune to that particular attack.

CHAPTER XXV

THE FUNGAL HABIT

MANY among the general public associate the idea of Fungi in the first instance with edible Mushrooms and with poisonous Toad Stools. Some people would also think of the Moulds that appear on any organic material, such as jam or bread, kept in a close damp atmosphere ; some would refer ruefully to Dry Rot ; perhaps others might also mention the Potato Disease, or the Rust of Wheat. By such references the leading types would have been indicated of that variable thing, the fungal habit. The forms which Fungi may assume are thus seen to be very diverse. It would probably surprise most people to learn that of all the divisions of the Vegetable Kingdom the Fungi present the largest number of described and recognised species. This fact goes along with the extraordinary differences that exist in the mode of life of these plants. They touch the wellbeing of Man in the most various ways, frequently beneficial but often detrimental. Many of them are notoriously poisonous.

The Fungi cannot properly be regarded as a coherent group based upon a real relationship. We may say with confidence that they form a division of the

Vegetable Kingdom that includes plants referable to several distinct sources by descent. But they show certain marked features in common. They are all pale-coloured in the sense that they have no chlorophyll. They have, in fact, given up—or at least they do not now possess—the full power of self-nutrition. In one form or another they depend for their supply upon organic material already built up from its inorganic sources, and live either as parasites or saprophytes. We may presume with some degree of certainty that this state is derivative, and that it has been acquired along more than one line of descent. This is indeed strongly suggested by the analogy of parasitism and saprophytism among Flowering Plants, where such states are clearly sporadic and derivative. As in them so in the Fungi the state of physiological dependence may sometimes have been of comparatively recent origin. On the other hand, we know that Fungi, in many respects similar to those now living, existed in early Devonian times. It is from considerations such as these that we conclude that they constitute a division of plants characterised rather by nutritional habit than by real relationship.

A further feature which the Fungi have in common is that their whole vegetative structure is based upon the delicate, colourless, cylindrical filament, or hypha, which is gifted with unlimited growth, and is often branched (Fig. 130). These hyphal filaments are so fine as to be for the most part invisible to the naked eye, but they are liable in the higher types to be massed together into parallel skeins, visible as white streaks traversing the medium ; or finally they may build up those large fruit-bodies which attract the attention of the ordinary observer. The Mushroom, the edible

Truffle, the Puff-Ball, and the large Shelf-Fungus that
projects from the trunks of living trees, are all examples
of these massive fruiting bodies (See Figs. 101, 133).
So is also that pest of ill-ventilated houses and of
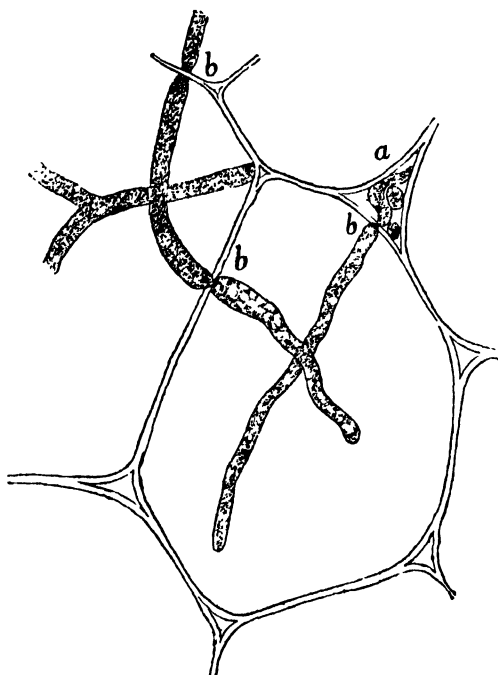
FIG. 130. —A SMALL PORTION OF THE CELLULAR TISSUE OF A
POTATO, traversed by fungal threads, or hyphae, of a parasite,
Pythium, which sometimes occupy the intercellular spaces, as at *a*;
sometimes they traverse the cell-walls. These hyphae of *Pythium*
are not divided by partitions or septa ; their granular protoplasm is
shaded. Highly magnified. (After Marshall Ward.)

wooden ships, the Dry-Rot Fungus, which, after
sapping the nature out of woodwork by means of its
fine digestive threads, works up the material won by
them into those flat weeping fruits, like livid pan-
cakes, that earn the descriptive name of *Merulius
lachrymans*.   The   outward   appearance   of   these
various fruiting bodies is so conspicuous that one

readily assumes that they form the whole Fungus.
But this would mean leaving out of account those
individual, fine-textured, thread-like hyphae which
always precede them, and are indeed necessary for
gathering the food supplies, without which the fruit
could not be formed at all. The general term
" mycelium " is often used in a collective sense to
include the whole connected system of these
nourishing threads.

In respect of fungal life as a whole, including on the
one hand the simple nutritive stage and on the other
the large fruiting bodies, comparison may be made
between these lowly organisms and that extraordinary
object *Rafflesia*, a flowering plant which we have seen
in a previous chapter to grow parasitically upon the
roots of a Vine. It was pointed out how the vegeta-
tive system of this parasite is reduced to mere threads,
like fungal filaments, that traverse the nutritive tissues
of the host (see Fig. 119, p. 276). But the flower borne
by it is phenomenally large and complex. The relation
between these two very different phases of a single
life is similar to that in the life of a Mushroom, Shelf-
Fungus, or Dry-Rot. The filamentous nutritional
stage, whether parasitic or saprophytic, is equally
essential for all of these plants, in that it paves the
way in the one case for a huge phanerogamic flower
with its abundant production of minute wind-borne
seeds ; in the other, for a large fruiting fungal body
with its vast output of minute wind-borne spores.

The apparent disproportion of the filamentous vege-
tative system to the large fruiting body at once com-
mands our interest : the simplicity of the one, and the
complexity of the other. Why should the parasitic
Flowering Plant thus degrade its vegetative organs to

a mere system of fine threads ; and why should it be
structurally so like the hyphal filaments that make up
the whole vegetative system or mycelium of one of
these Fungi ?   There is a common physiological
reason which has probably dictated the filamentous
structure in both, though they are drawn from quite
different divisions of the Vegetable Kingdom.   It is
that since the filaments are very fine in texture they
present to the medium which they traverse, and from
which their food is to be absorbed, a very large pro-
portion of surface to bulk.   We may assume that the
whole of this surface is absorptive.   Whether the
source be, as in *Rafflesia*, the living tissues of the Vine-
root, or as in the Mushroom the highly organic sub-
soil of old pasture, or as in Dry-Rot the damp timber
of a house or a ship which it perforates, or as in the
Shelf-Fungus the wet heart-wood of a living tree—in
all of these the primary requirement is the same, viz.
an extensive absorbent surface for securing the ma-
terial that the filament is able to extract out of the
nutrient medium.   This is in fact the rationale of all
fungal hyphae.   Though this large proportion of sur-
face to bulk is necessary for acquiring their borrowed
or stolen nutrition, still the simple hyphae may at any
point be massed together to form a large fruiting body,
or they may even build up tuberous storage-structures,
or sclerotia, comparable in size and content to those
seen in Flowering Plants (Fig. 131).   *Rafflesia*, however,
when forming its huge flower-bud, simply reverts to
the original complex structure characteristic of Flower-
ing Plants.

A special interest belongs to these fungal filaments
that initiate and carry on the habit of parasitism, for
they give a good opportunity for studying how the

attack is in the first instance made, and infection
started.   Let us imagine the case where the victim is
an ordinary Flowering Plant.   Its aerial parts are well
protected by the continuous skin of cuticle, covering
the superficial epidermis.   This naturally offers an
obstacle to the attack.   But in all the higher land-
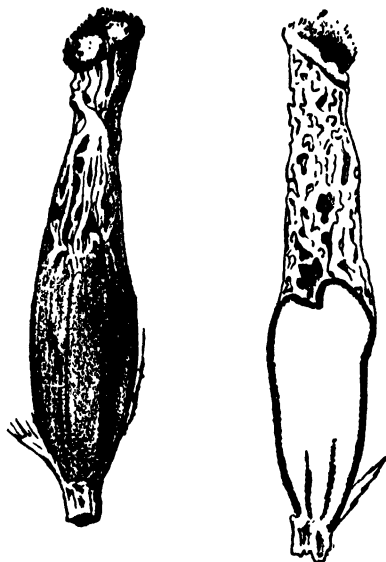
FIG. 131.—SCLEROTIA OF ERGOT OF RYE (*Claviceps*), a fungus
that infects the pistil of the Rye, and other grasses, forming in autumn
a large dark coloured body consisting chiefly of fungal tissue stored
with food-material.   It germinates in the spring, forming the
fruiting bodies of the fungus.   To the left, a sclerotium seen from
the outside; to the right, one in section ; above is the style of the
Rye, surrounded by the " Honey dew " or summer stage of the Fungus.
(After Marshall Ward.)

plants the pores of the stomata, gaping widely as they
do during the day, offer each a weak point at which,
as through an open door, the delicate fungal filament
may grow.   It would thus make its way into the ven-
tilating channels of the host, and so it may reach the
moist wall surfaces of the living cells.   This is a com-
mon source of infection, as it is certainly the easiest :
and it is made use of by such destructive agents of

disease as the Potato Blight, and the Rust of Wheat. Another common source of infection is by entry of the Fungus through wounds of the host-plant. Winds break, and browsing animals often gnaw the epidermal covering. Wherever the inner tissues are exposed fungal spores may alight, and infection follow on their germination. But many Fungi possess the power of infection by actual perforation of cell-walls. Detailed
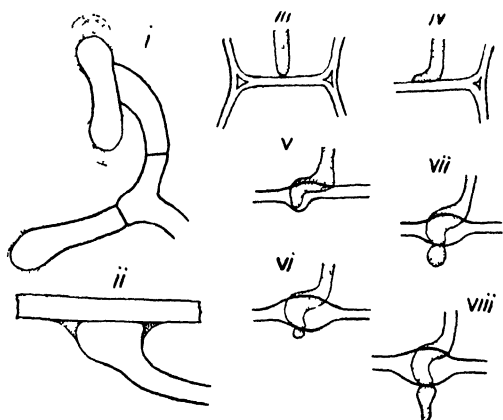
FIG 132 – SUCCESSIVE STAGES OF THE PENETRATION OF A CELL-WALL OF THE LILY BY THE HYPHA OF THE FUNGUS CAUSING THE LILY-DISEASE   i, shows the ends of a branched filament, with the drops of digestive secretion; ii, the same spread out over a surface of glass; iii-viii, successive stages of perforation by its means. (After Marshall Ward.)

study has shown how this attack is carried out. Well-nourished filaments have been seen to secrete on their tips a highly refractive juice, which on contact with a surface of glass or of a cell-wall spreads out over it (ii). The effect on a cell-wall is that its substance swells and softens ; the filament then sinks quietly into the softened substance, and later emerges on the other side of the wall (Fig. 132). By such means the invader can enter a superficial cell or pass onwards from cell to cell of the internal tissue. The secretion by which this is done has been extracted in quantity,

and it is found to act by swelling and softening cell-walls apart from the living filament ; in fact, it acts as a ferment. By this means a parasitic Fungus practically digests and eats its way through its victim. Its success will depend upon the digestive power of its secretion ; but it is open to the victim to protect itself by indigestible walls, or by counter-secretions which can check the attack. Parasitic penetration thus appears to be largely a question of secretion of digestive ferments, and it is probable that saprophytism depends for its success upon similar means, acting upon dead organic substance. For instance, it has been shown that the filaments of the Dry-Rot Fungus can thus attack and traverse the cell-walls of damp and alkaline wood : but this, being dead, has no power of physiological resistance such as resides in the tissues of a living plant.

Thus equipped with ferments, whether for saprophytic or for parasitic nutrition, a mycelium can spread widely, and acquire as it does so sufficient material to enter upon fruit-formation. The final feature in this is the production of vast numbers of very minute spores ; and we might here again point out the parallel between the minute spores, and the very numerous but minute seeds of *Rafflesia* borne by its enormous flower. The fruit-bodies of Fungi are sometimes quite small, but often they are large. Common types of them are known as Mushrooms, Toad-Stools, Puff-Balls, Shelf-Fungi, Truffles, and Morels. These large and often brightly coloured bodies produce, either externally or internally, the minute unicellular spores that are readily spread like impalpable dust by the lightest breeze. A touch on the tough skin of a ripe Puff-Ball, making it act like

a bellows, will blow out the dry spores in a dense cloud, and the slightest breath of wind will then scatter them far and wide. Here, as elsewhere, the more numerous these germs are the greater the probability of successful propagation, and the wider the spread. This is the biological explanation of these large and most prolific fruits, the size and complex structure of which appear to stand in such strange antithesis to the simple mycelium that bears them. But both of these divergent phases of fungal life may be held as specially adapted to their conditions, and are obviously fitted for the performance of their respective duties, the first nutritive, the second propagative.

Spore production is usually restricted to definite fertile surfaces of the fruit-body, either external or internal. Such a fertile surface is called an hymenium. In the Common Mushroom it covers those pendent radiating " gills," which are pink when young, but turn brown as they grow old. The change in tint is caused by the fact that the mature spores have brown walls (Fig. 133). A simple demonstration of this may be given by laying a fully expanded Mushroom, gills downwards, upon a sheet of paper. After twenty-four hours an exact plan of the gills will have been printed by the numerous brown spores that have been shed from them. In the Shelf-Fungi the hymenium is like a honeycomb, with multitudinous pores, hence the name *Polyporus*. Treated in the same way the spores would here be deposited on the paper in little round heaps. The fact is that the gills and pores are merely ways of providing for an enlarged hymenial surface, by throwing it into folds, with a correspondingly increased surface for the output of spores. Examination of the structure of the fruit-body itself, and

especially while it is young, shows that, though it appears solid and massive, it is made up of closely interwoven and compacted filaments. It does not
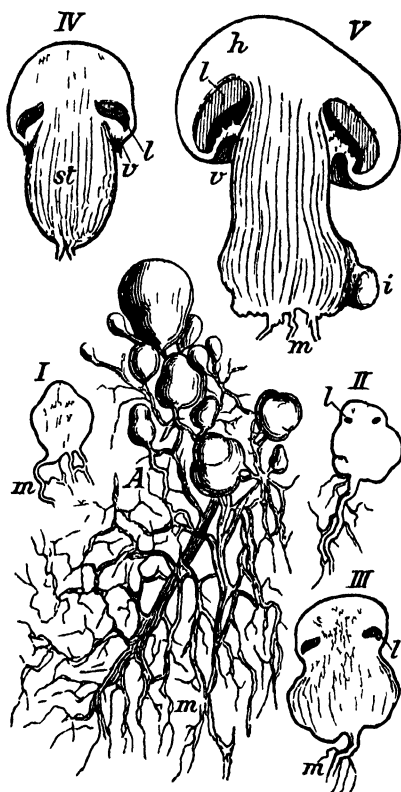
Fig 133 — Illustrations of the Formation of Mushrooms from the Mycelium (*m*) and of the adult fruiting body (V) with its pileus or head (*h*), its gills or lamellae (*l*) and the protective veil (*t*) these parts being borne on a stalk (*st*) The Mycelium (*m*) is formed first and nourishes itself in the organic soil and the small button mushrooms formed on it grow later into the adult fruiting Mushroom Natural size (After Sachs)

consist, as the bodies of the higher plants do, of a continuous tissue built up of cells following a common law of growth, and originating from a common source by cell-division. The structure of a Fungus is rather like a mass of cotton-wool, with the threads more or

less closely compacted but independent (Fig. 134). The older botanists described this type of structure as " tela contexta." For us the conclusion follows that, however large and apparently solid a fungal fruit may appear to be, in its real nature it is nothing more
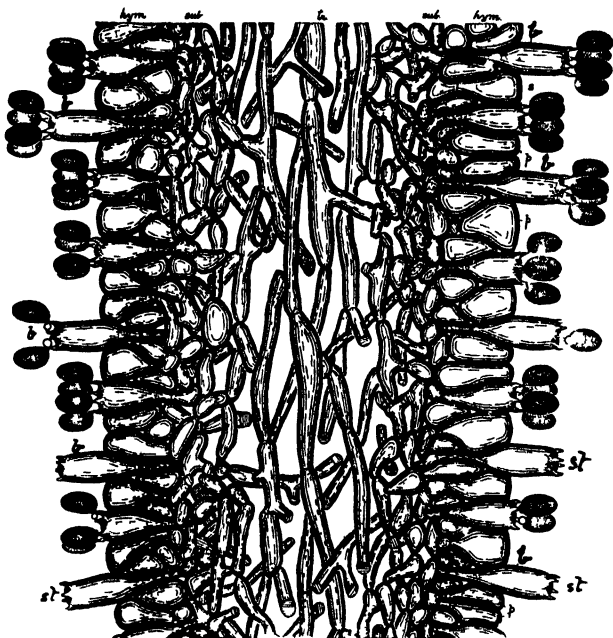
FIG. 134.—SECTION THROUGH PART OF A GILL OF A TOAD STOOL (*Coprinus sterquilinus*) highly magnified showing the superficial hymenium (*hym*) the sub hymenial layer (*sub*) and the trama (*tr*) all composed of interwoven filaments or hyphae composing a false tissue The basidia (*b*) each bear four carpospores or where old only the sterigmata may be seen (*st*) from which the spores have been already thrown off (After Buller)

than a compacted and complex tangle of filaments each in itself simple, and similar in its nature to those hyphae that form the earlier nutritive phase. And so we may link even the most elaborate of these fruiting bodies structurally with that simple filamentous form which they may very likely have inherited from an Algal ancestry.

We thus see that the Fungi possess a mode of construction that is extremely flexible. It passes readily from the finest thread, invisible to the naked eye, to the closely aggregated mass of threads, small or great, which may in extreme cases form a fruit-body even a foot or more across. The flexibility of this mode of construction offers great biological opportunities. The absorptive surface may be proportionately great in the simple filament, though the storage space be insignificant; but by massing the filaments together these proportions may be reversed so far as their functional efficiency is concerned; and all intermediate states would be available as required. Such flexibility is peculiarly suitable for plants that take their nutrition at second hand, as the Fungi do. This habit has doubtless been connected very closely with their remarkable evolutionary success. The large proportion of surface in the isolated filament provides for ready absorption of organic materials. To this must be added the powers of digestion shown in some of them by the secretion of ferments effective either parasitically or saprophytically. They are thus able not only to absorb soluble substances, but also by their digestive juices to prepare for absorption materials not soluble before. When to these advantages we add their exceptional powers of propagation by spores produced in untold numbers, and small enough to be scattered as impalpable dust by the lightest breeze, we arrive at some understanding of the factors which have made the Fungi so prevalent in number of species, and widespread as individuals.

CHAPTER XXVI

FUNGAL PARASITISM

THERE are no plants that possess greater resource in the acquisition of food than the Fungi. If we include the Bacteria under that general title, as well we may, for their characters and mode of life fully justify it, the statement is certainly true. But the Fungi play their part in the down grade of metabolic change ; their vital activities lie between the absorption of material already gained by photo-synthesis carried out by the green cells of other plants on the one hand, and its restitution to the original inorganic sources on the other. In fact, fungal life is katabolic. But the organic material that serves them as food may be presented to them in different ways, and frequently Fungi appear to be strangely selective. A given species will develop freely on a certain substratum and no other, though other Fungi again may appear to be almost omnivorous. Digestive ability rather than any other form of choice dictates their habit. Fungi feed where they can, and those that are of the highest digestive capacity are those that are the most catholic in their diet. These have the best chance of survival and of spread.

A broad distinction may be drawn between those

that feed on living organisms, which are ranked as parasites, and those that use dead material, which are ranked as saprophytes. But the distinction between these two modes of feeding is blurred. It not unfrequently happens that an attack may be made first on a living subject, as for instance by *Pythium*, the damping-off Fungus, which attacks and kills seedlings such as Cress. But the death of the victim does not put a term to the life of the assailant ; it continues to batten on the corpse. In a technical sense, it passes from a parasitic to a saprophytic mode of nutrition. On the other hand, Fungi living habitually as saprophytes may when well nourished attack the living plant, and thus become parasites. An example is well known in *Sclerotinia*, a mould which can only penetrate living tissue after a period of high saprophytic nutrition ; for instance, on the juice of stewed prunes. It may be regarded as a Fungus which is in course of education for passage from the saprophytic to the parasitic life. It appears impossible to lay down any general rule of priority either of parasitism or of saprophytism for Fungi at large, and it is only in certain cases that the one habit or the other can be assigned to any definite group.

Where parasitism exists the source of food may sometimes be the living animal. Examples are seen in the salmon disease (*Saprolegnia ferax*), or in the Fungus, *Cordyceps*, which grows on caterpillars in New Zealand, or on cockroaches at home. *Empusa* is common on house-flies in autumn, when they may be found fixed by the Fungus on window-panes, with a zone of sticky spores shot off from the parasite, and adhering to the glass like a halo. But fungal parasitism is much more common on the plant-body, and

often it causes very destructive diseases of valuable crops. One or two illustrations will suffice to show how the invasion is carried through ; these have been selected so as to illustrate variety in the method of attack, and in the behaviour of the host to the invader.

THE DAMPING-OFF FUNGUS

When Mustard and Cress are sown thickly, and kept too warm and moist, as they often are by the amateur gardener, the seedlings are liable to " damp-off," the young plants quickly rotting with an unpleasant smell.
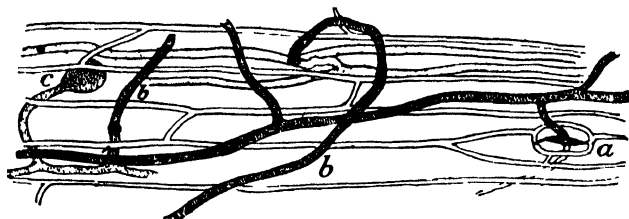
FIG. 135.—PIECE OF TISSUE OF CRESS, the cells of which are given in double outline. The cells are traversed by hyphae of *Pythium*, their contents being shaded. The hyphae run in all directions; at *a* one passes through a stoma. Highly magnified. (After Marshall Ward.)

The first sign of the disease is the collapse of the seedling owing to shrinkage of its cortex, and this appears usually at some point above the soil-level. Microscopic examination of the tissue at that point shows that it is riddled through and through by the rather coarse hyphal threads of the Fungus *Pythium*. The threads traverse the cell-walls of the host with the greatest ease, killing the cells as they go (Fig. 135). They may spread from plant to plant in a crowded culture, especially when their growth is promoted by damp conditions. The first entry may be either through a stoma or by direct perforation of cell-walls. The effect on the plant is fatal, and the Fungus

continues to feed as a saprophyte, often fruiting in that state of dependence. Obviously there is no physiological finesse about this attack, which is crude and voracious in method, and deadly in its result; while the victim shows no sign of effective resistance.

POTATO MILDEW

An allied Fungus, *Phytophthora infestans*, causes the Potato disease, which led to the great Irish famine of

FIG. 136.—A POTATO LEAF SHOWING SPOTS AND PATCHES OF POTATO DISEASE DUE TO THE POTATO MILDEW (*Phytophthora infestans*). In the darker patches the tissue is quite dead. The margins of the spots would show hyphae of the fungus projecting from the surface, and bearing the minute, dusty conidia. (After Sorauer from Marshall Ward.)

the years 1845-1850. It makes its appearance as spots upon the stems and leaves (Fig. 136). At first these spots are small and pale coloured, but as each enlarges its centre turns brown, showing that there the cells of the host are dead. The spots may extend and run together, and presently the whole leaf or shoot may be affected. Microscopic examination here shows a less virulent attack than that of *Pythium*. The infection may be through the pore of a stoma, and thus

the Fungus gains access directly to the ventilating
channels of the leaf ; or infection may be by perfora-
tion of the superficial cells. But the hyphae travel
either through the intercellular channels, or they bur-
row through the soft middle part of the cell-walls.
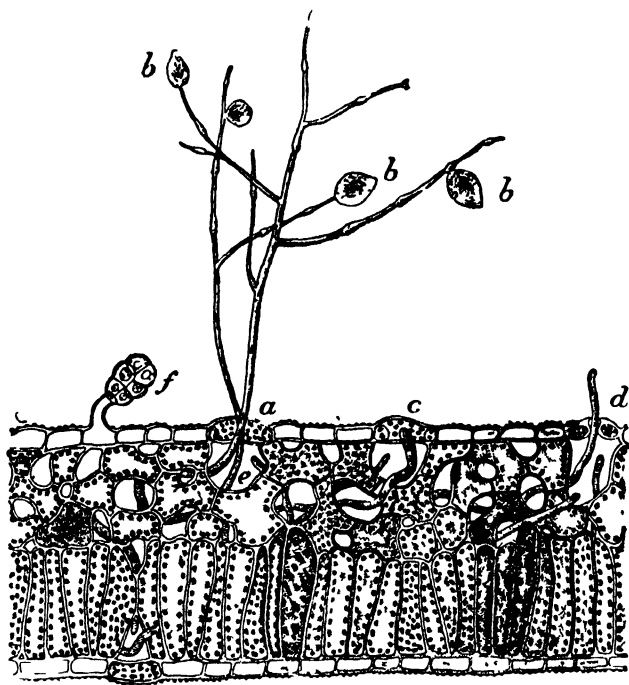
FIG. 137   SECTION OF A POTATO LEAF, in the tissues of which is the
mycelium of the Potato Mildew   The hyphae run between the cells
and send out through the stomata a c d their aerial branches which
bear conidia b   The dark parts of the tissue of the leaf show where
the cells are dying from the effects of the parasite   Highly magnified
The normally upper surface of the leaf is here turned downwards   f is
a glandular hair of the Potato   (After Marshall Ward)

They do not perforate the cells as a rule, and so the
attack appears to be less savage than that of *Pythium*.
But against this is to be set the profuse method of
multiplication of the Fungus by multitudinous wind-
borne spores, each of which may bring about a fresh
infection, or even more than one (Fig. 137).   The

net result is that the Potato plant is overcome by the
disease, which may even penetrate downwards to the
tubers.   There it lies dormant and inactive as a " rest-
ing mycelium," ready to make a fresh attack in the
ensuing season if such tainted tubers are used as
" sets."   Clearly there is here some degree of toler-
ance of the disease by the host.   There is, however, in
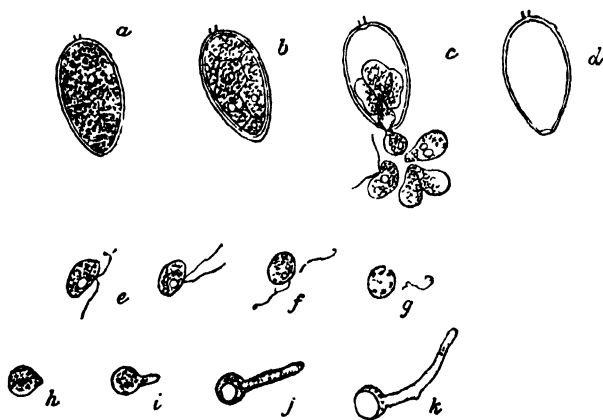
FIG. 138.—STAGES IN THE GERMINATION OF ONE OF THE CONIDIA
OF POTATO-MILDEW.   *a*=the ripe conidium in water; *b*=contents
breaking up into blocks, which separate and escape (*c*, *d*) as minute
kidney-shaped motile bodies (*e*), each with two cilia. *f* show these
coming to rest after moving in the water, and losing their cilia.
h. i, j, k =stages of germination, and of putting out a tube by which
infection of the Potato-leaf may follow, the whole incident having
happened in a water-drop on its surface. Highly magnified. (After
Marshall Ward.)

some strains of the Potato an actual power of resist-
ance to attack so strong that the Fungus cannot gain
a foothold.   Such strains are accordingly styled " im-
mune varieties."   These are now carefully selected
and bred for his field crops by Man.   It is upon these
that the future cultivation of Potatoes will largely
depend.   Man's profit from the crop will, in fact, be
influenced by the degree of resistance of the host to
the parasite.   The climatic conditions during growth
will also tip the balance favourably or the reverse.

Relatively dry conditions will help the Potato, but wet weather will favour the parasite. This is indeed a point of special importance, for the spores germinate in drops of rain water or dew deposited upon the leaves or stem (Fig. 138). It is not overstating the case to say that the balance of digestive attack, as against the factors that lead to protective immunity, may be directly translated into the minus or plus of the potato-farmer's banking account.

RUST FUNGI

A still further degree of tolerance of the invading Fungus by the host-plant is seen in the common disease called Rust of Wheat, the incidence of which costs farmers at home and abroad untold millions of money yearly; for the Wheat plant, impoverished physiologically though not killed by the parasite, produces a short crop of grain (Fig. 139). The disease appears on the Wheat in early summer, showing itself by the rusty colour of the foliage due to the spores produced in immense
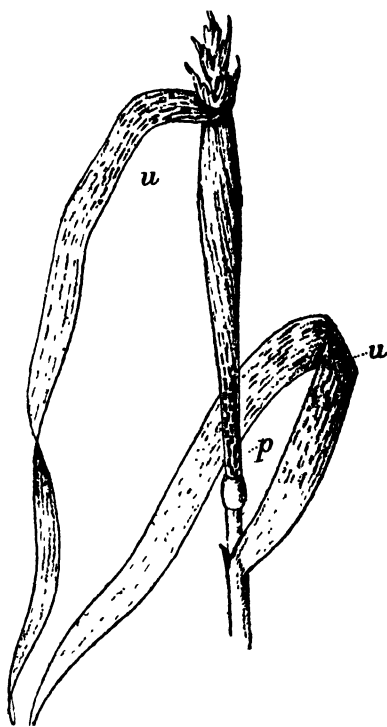
FIG. 139.—UPPER PORTION OF A STALK OF WHEAT, with spots of infection by Wheat-Rust on the fast ripening blade and sheath. (After Marshall Ward.)

numbers like impalpable dust. Being dry, these
are readily carried by any breeze. If a spore falls
on a healthy leaf it may germinate in a drop of
rain or dew, and the germinal tube entering a stoma
establishes itself in the ventilating passages, and
causes a new infection. In close contact with the
moist cell-walls the hyphae derive nourishment, though
the cells of the host that yield it are not killed. The
cells struggle on, though always with the disability
that what they gain by photo-synthesis is apt to be
stolen from them by the parasite. The Fungus does
not invade the conducting tracts, nor the hard
mechanical tissue. It restricts itself to the green
nutritive tissue, where naturally the food supply is
handy ; in fact, it attacks its very source. Since no
vital point is destroyed, the plant may still live.
There is some degree of elegance in this parasitism,
which owing to the absence of virulent perforation is
tolerated. But the effect of the disease appears in
the diminished crop, while the individual grains may
be shrivelled and of inferior market value.

The Rust Fungus is an example of that strange
mode of life, common for many allied Fungi, and
shared by such animals as the Liver Fluke, and the
Tape Worm, viz. that of living successive stages of
the life-cycle on two quite distinct hosts. This has
been called heteroecism, and its occurrence both in
plants and animals seems to suggest that it must be
of some real advantage to the organisms that show it.
In the Rust the alternative host to the Wheat is the
Common Barberry, where the brightly coloured disease
spots appear upon the leaves in early summer and are
known by the descriptive name of " cluster cups "
(Fig. 140). So different is this from the stage on the

Wheat leaf that the two were at first held as being
due to quite distinct organisms. It has long been
known that the Barberry has something to do with
the prevalence of Rust of Wheat; indeed, the sense
of this was so strong that so early as 1755 the State of
Massachusetts prescribed under the " Barberry law "
the eradication of that plant from the province with
a view to checking the disease. Sir Joseph Banks first
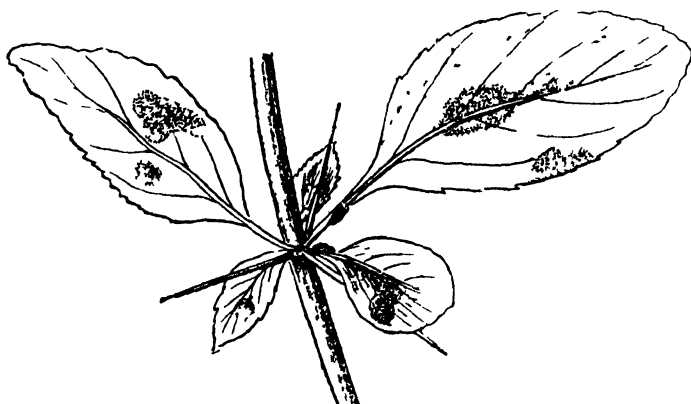
FIG 140 —PART OF A SHOOT OF THE BARBERRY with its leaves
attacked by cluster cups (*Aecidium Berberidis*) which forms yellow
swollen cushions on the leaf blades and stalks the cups opening on
the lower leaf surfaces (After Marshall Ward.)

suggested in 1805 that the rust on Wheat and cluster-
cups on the Barberry were merely stages in the life
history of the same parasite. But it remained for De
Bary in 1865 to demonstrate by actual cultures that
this is the real fact. The whole life-history of the
Fungus is a complicated one, and it need not be
described in detail here. But as an example of fungal
parasitism the stage upon the Barberry leaf has this
special interest, that the attack of the parasite in-
duces a marked response in the host. The infected
spots are bright red or yellow, and are much thicker
than the healthy parts of the leaf. Sections show that

the air channels are densely occupied by the filaments of the parasite, but the cells of the host retain their vitality, and by their enlargement have produced the swelling that is seen (Fig. 141). Here then is a still more marked degree of toleration ; indeed hypertrophy of the host follows on the infection. In some of the
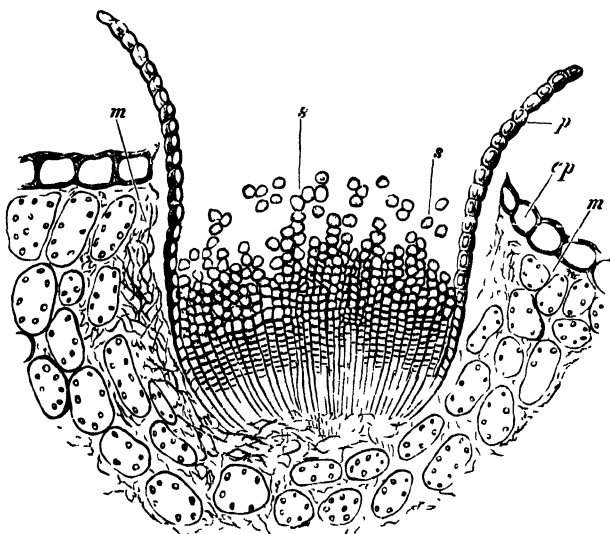
FIG 141 —SECTION THROUGH A SINGLE AECIDIUM CUP on the leaf of the Barberry, seen with lower surface uppermost   *m* intercellular mycelium ; *p* peridium ; *s* chains of spores, easily detached : *ep* epidermis of leaf   (After Strasburger) (142)

Rust Fungi the malformation is even more noticeable than here, as seen especially in other species that invade the Nettle, or the Juniper. Clearly the Rust Fungi differ in their power of attack from such Fungi as *Pythium* or *Phytophthora*, for they do not destroy the host. As a rule they invade the leaves only, and where there is a seasonal leaf-fall, or where the host dies down in autumn, it is temporarily free of the trouble ; but it is liable to a fresh infection in the ensuing season.

The Rust Fungi are particularly numerous, and peculiarly selective in regard to their hosts. Often definite species of them are restricted by their powers of penetration to definite genera or species of Flowering Plants. Sometimes distinct fungal strains appear to be able to discriminate between species very closely allied. This has been seen in the Rusts upon species of *Bromus*. Here the several Fungi are to all appearance alike morphologically ; but physiologically they have been found on experiment to penetrate each its own specific host, while others cannot do so. This is indeed a high degree of physiological discrimination on the part of the invader, or of resistance on the part of the victim. It may be upon some such delicate balance that the survival or extinction of a host-plant in a given district may actually rest.

Any reflective person, in presence of such ideas as these, will feel how tenuous is the thread upon which may hang the success, or even the life, of a people. Two great economic catastrophes are known to have followed upon an increased virulence of infection by a Fungus producing epidemic disease on important crops. A tipping of the exact balance of attack and resistance in favour of the assailant produced both the Irish Potato famine, and the failure of the Coffee crop in Ceylon. In both instances a whole population was disorganised; the Irish peasants were starved, and the population reduced by emigration following upon the failure of their Potato crop ; and the Ceylon planters were well nigh ruined by the failure of their staple—Coffee. In neither case was the Fungus a new one, but a type already recorded and known. In both the passage to the epidemic state may be ascribed to a disturbance of the delicately poised balance between

invader and host. Experiences such as these, and
many more which have produced less striking re-
sults, have stimulated the study of intrusive Fungi,
and the conditions under which they establish them-
selves as parasites upon cultivated crops. They have
brought into existence a new profession—that of the
plant-pathologist—whose duty it is to make a specia-
lised study of plant-diseases. In particular, he must
be able to diagnose the organisms that cause disease,
and to advise on remedial measures. An adequate
knowledge of applied fungology is tending to become
one of the necessary conditions of successful agricul-
ture on the Imperial scale, and the due education and
support of those who pursue it is rapidly becoming
one of the pressing obligations of Empire.

The functions of the plant-pathologist are cognate
with those of the animal- or even of the human-patho-
logist. So far as the diseases they study are of fungal
origin, all of them are observing intensively the oppos-
ing sides of the struggle between an invader and a
victim. The invader may be a minute Bacillus, or a
filamentous Fungus, or even a more highly organised
animal or plant. But in any such relations between
the invader and the host the question of disease is one
of the balance of physiological power, as shown in the
first instance by individual cells. The final result,
whether it be successful resistance, or continued
disease, or even death itself, is the outward and cumu-
lative record of the success of the one or the other
party in the physiological struggle.

CHAPTER XXVII

BACTERIA

THOSE minute organisms known as " Bacteria " are
most intimately connected with the well-being and
even with the very existence of Man. They every-
where accompany organic life, and are present in vast
numbers. They have no chlorophyll. Speaking gen-
erally, their methods of nutrition are like those of other
parasites and saprophytes, whether these be Flower-
ing Plants or Fungi. Thus they take their place with
them in relation to the downward grade of metabolic
change, but they work out their nutrition by irregular
and singularly varied courses. It is therefore not
uncommon to look upon the Bacteria as organisms
apart and peculiar. But if a broad physiological view
be taken, it appears that they are not essentially
different from other plants ; and in particular they
behave like other Fungi, with which they may pro-
perly be ranked. It is, however, probable that they
came into existence along a different line of evolution
from the ordinary filamentous types.

The Bacteria are unicellular, but their cells may
sometimes remain attached together after division,
thus forming filaments, films, or even cubical masses.
Each bacterial cell has a protoplasmic body without

any definite nucleus, and it is often protected by a
superficial wall. Many Bacteria are motile in water
by means of lashing cilia. Their increase in numbers
is rapid and extremely simple. It is by fission : that
is, the division of a single unit into two equal parts.
Their size is very minute, some of them being so small
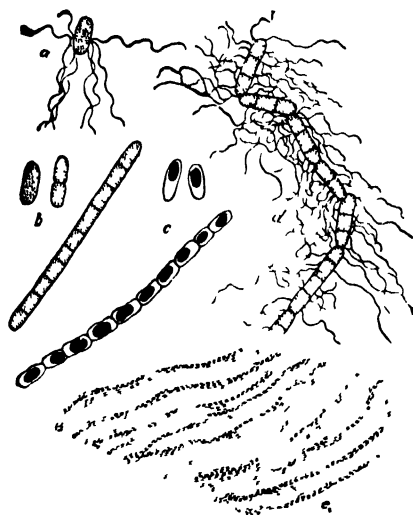
Fig. 142 – Different forms taken by the Hay Bacillus
(*B. subtilis*) *a, d* motile cells and chains of cells *b* non motile cells
and chains of cells *c* spores from the zoogloea *e* the zoogloea
(After A Fischer *a d* 1500 *e* 500 From Strasburger)

as to approach or even to pass the limit of micro-
scopic observation.

The Hay Bacillus (*B. subtilis*) will serve as a good
example of the life of a Bacterium, and may show how
it can be controlled. The plant may easily be ob-
tained in a decoction of hay in boiling water (Fig. 142).
If the fluid be cooled, filtered, and set aside for forty-
eight hours in a warm place, it will then be found to
be swarming with the ciliated motile form of the
Bacillus (*a*, *d*), while later the surface of the liquid
would be covered by a scum, which is the so-called

zoogloea-state of the plant (e). Here the cells appear connected in filaments and non-motile. Later still each cell may form a resting spore within (c) ; here the individual cells are held together as a scum by their gelatinous walls. It is in the state of the spore that the plant exists in old hay ; in this state it can resist the temperature of boiling water, consequently many spores remain still living in the decoction. These on cooling may germinate into active Bacilli, and propagate rapidly by fission so long as the conditions are favourable. But when they are checked, for instance, whenever the food supply is exhausted, they pass again into the resting state. A single boiling of a fluid may kill some of them, but it cannot be depended on to kill them all, since in the spore-state they are resistant. To obtain complete sterilisation, it would be necessary to raise the fluid to a higher temperature than that of boiling water. But a simpler way to obtain complete sterilisation is, after boiling once, to keep the culture at a favourable temperature of 37°C. for forty-eight hours. During this time the living spores will all germinate and pass into the motile but vulnerable state. Then a second boiling will completely sterilise the fluid. This method is commonly used in the preparation of sterile media for the experimental culture of Bacteria.

Under favourable conditions *Bacillus subtilis* divides once in about twenty minutes. If this pace be continued by all the progeny for eight hours the number thus derived from a single parent would be over sixteen millions. This illustrates the rapid increase in numbers of Bacteria. It depends in the first instance upon a supply of organic food, which they may derive from very varied sources. Being like the

filamentous Fungi saprophytic or parasitic plants, they depend for their food and energy upon organic sources. They break down more complex compounds, originally derived from the activity of green cells of plants under sunlight, into simpler ones, the end-products being again carbon-dioxide and water. But in the course of this change many steps may intervene, and bye-products be formed which are sometimes useful, but often harmful to other organisms, and to Man himself.

There are important external checks beyond the mere question of suitable food, which control the activity or even the life of Bacteria. Many of these plants are susceptible to the influence of light. It has been experimentally shown that the blue-violet rays are effective in killing certain Bacteria. This fact is of prime importance to health, for sunlight thus offers a natural and far-reaching check upon many harmful germs. The relation of Bacteria to the free oxygen of the air is also a matter of importance. Plants may be distinguished as either aerobic or anaerobic, according to their dependence upon the presence of free oxygen or their independence of it—though there is no sharp line between these modes of life. Ordinary plants are naturally aerobic, and so are certain Bacteria which when motile are attracted by free oxygen, and crowd round air-bubbles. The Hay Bacillus is aerobic, but some of the most deleterious are anaerobic ; a well-known example is the Bacillus of Tetanus, or Lockjaw. Such organisms flourish in the absence of free oxygen. It is this mode of life, together with the toxines or secondary products which result from it, that makes the Tetanus Bacillus specially dangerous in wounds.

Bacterial germs are widely diffused in air, water,

and soil ; also on and within living organisms whether
animals or plants. They are less frequent in, or even
absent from the purer waters of the open ocean, or
the higher strata of the atmosphere. Their activities
are so various that it must suffice to quote a few
examples that specially affect the well-being of Man.
Among the Bacteria that live in water the definitely
filamentous *Crenothrix polyspora* is notorious for chok-
ing the pipes of water-supply, and making the water
undrinkable, though apparently not poisonous (Fig.
143). Many towns on the Continent and at home have

FIG. 143 — *Crenothrix polyspora*, in Iron Bacterium that infests
the water conduits of towns. A mature specimen. (After Ellis.)
(2/0)

suffered from it ; it is probably world-wide in distri-
bution. Being an Iron-Bacterium it finds special
opportunity for development in the water-conduits
of towns. It shares with other Iron-Bacteria the
power of converting oxide of iron to the hydrated
oxide, which is then deposited as a rusty crust invest-
ing its cells. When these are massed together they
appear as those ochre-coloured deposits of " bog-iron-
ore," not uncommon in the beds of ferruginous
streams. This is an example of a filamentous
Bacterium which grows attached at its base to solid
objects. Somewhat similar are the Sulphur-Bacteria,
which grow in sulphurous springs. From sulphur-
etted hydrogen they separate sulphur, which is then
deposited in their cells.

The tubercles of the Leguminosae have already
been described in Chapter VII. The Bacillus that

causes them enters through the soft tip of the root-hair, and working its way down into the tissue stimulates the formation of the tubercle, and co-operates with the tissue of the root in the fixation of nitrogen from the air.   But the invader is itself finally digested by the cells of the plant it has entered, which thus increases its own supply of nitrogenous material. This is an example of the beneficent relation of a Bacterium with a host, and we have seen how it exercises a
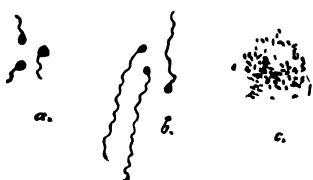
FIG 144 – NITRIFYING BACTERIA
present in humus soil   (After Wino
gradsky)   a   *Nitrosomonas europaea*,
from Zurich   b   *Nitrosomonas java-
nensis*, from Java   c   *Nitrobacter*,
from Quito   (From Fischer *Vorl u
Bacterien*) (1000)

far-reaching influence upon agriculture.   Not less important is the action of the Bacteria that carry out " nitrification " in the soil. Various putrefactive organisms, breaking down the nitrogenous compounds in humus soil, liberate the organic nitrogen which they contain in the form of ammonia. This ammonia must be " mineralised " before it can be used again by green plants. It is oxidised in the soil, and combined with a base to form nitrate. This process is known as " nitrification," and is carried out by certain Bacteria everywhere present in the soil (Fig. 144). These two examples will serve to illustrate the importance of bacterial action in agriculture.

Bacteria have also wide-reaching effects in manufacture.   For instance, acetic Bacteria convert alcohol into vinegar ; butyric Bacteria, attacking the middle lamella of the cell-walls, cause the " retting " of flax and hemp when sunk in water ; the resistant fibres are thus freed from the softer tissues. Bacteria take part in the preparation of indigo ; while the flavours

of butter, cheese, and of tobacco depend for their market-value upon the action of specific Bacteria, which give that exact type of partial decomposition of their constituent substances upon which quality depends.

We shall be most interested, however, in those Bacteria that affect Man and other animals. Many flourish on the mucous membranes of the mouth, nose, and alimentary canal, etc., and accompany the indi-
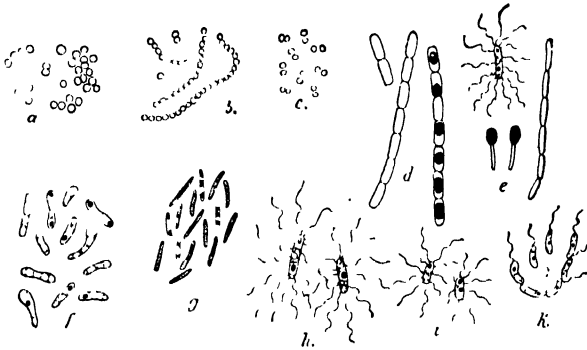
FIG. 145   VARIOUS BACTERIA THAT CAUSE DISEASE. *a* Pus cocci; *l* erysipelas cocci; *c* gonorrhoea cocci; *d* bacilli of splenic fever; *f* diphtheria bacilli; *g* tubercle bacilli; *h* typhoid bacilli; *i* colon bacilli; *k* cholera bacilli   (From A. Fischer, *Vorl. ü. Bacterien*)   (about 1500)

vidual through life without doing harm. But others are parasites that enter the tissues and cause active disease. Thus suppuration is caused by various *Cocci*: acute lobar Pneumonia by a *Diplococcus* ; Anthrax, or malignant pustule, by *Bacillus anthracis* ; Lockjaw by *Bacillus tetani* ; Tubercle by *Bacillus tuberculosis* ; Cholera by the " comma-bacillus," *Vibrio cholerae*, etc. (Fig. 145). The actual intrusion of the organism is the first essential of disease, but the serious consequences are due to the active poisons, or toxines, produced by the micro-organisms, and liberated into the system of the host. The host defends itself by

the action of the white blood-corpuscles, and other cells, which take up and digest the invading Bacteria. These cells have accordingly been called " phago- cytes," or devouring cells. The process of defence is physiologically similar to that carried out by the digestive cells in the mycorhizic Orchidaceae (see Chapter XXIV, Fig. 129). But in infective disease of the animal body there is also another line of defence, which forms the foundation of the serum-treatment now so widely applied both to domestic animals and to Man. It is based on the fact that in certain in- stances, when a bacterial toxine is introduced into the circulation of an animal in suitable amounts, there is developed in the blood-serum of the animal a sub- stance which has the property of neutralising the toxine, and it is therefore called an anti-toxine. Various specific antitoxic sera have thus been pre- pared, and are used either as preventive or as curative agents. This is not the place to discuss further the phenomena of immunity, but it may be stated that immunity is of two types : it is directed either against the growth of the Bacteria, on the one hand ; or against the action of their toxines, on the other.

The invasion of plant-tissues by Bacteria does not appear to be so common as that of animal-tissues. The reason probably is that the cell-walls prove an efficient obstacle to infection. But a good example is seen in Crown-Gall, a disease which occurs on various cultivated plants, and especially on fruit trees, causing swellings or galls. It is prominent on the Paris Daisy (*Chrysanthemum frutescens*), in which it is very de- structive to nursery stock, being highly contagious. The organism that causes the disease has been iso- lated, and it is called *Bacillus tumefaciens*.

The examples thus mentioned suggest some of the various ways in which the welfare of Man may be affected by these minute organisms, whether favourably or the reverse. But however peculiar or complicated their action may be, still the life of Bacteria is such as to rank them with other Fungi ; while the vital processes which they show are still more broadly comparable with those seen in other representatives of the Vegetable Kingdom. They are, in fact, plants which work out, each in its own way, the imperative problem of nutrition.

CHAPTER XXVIII

SCAVENGING AND SANITATION

SCAVENGING is the duty of a large department in any modern city, and on its performance the well-being of the community depends. It consists in the removal of matter no longer in use. That matter may be organic or inorganic. It is the former that presents by far the more critical problem, for organic bodies are liable to those changes which are included under the general word decay, the effects of which may be not only unpleasant but dangerous to health. The general problem of sanitation, in the solution of which scavenging plays so important a part, is not a new one; nor is it a mere consequence of the modern growth of urban life, though it is in a crowded population that its solution becomes an insistent need. Its importance does not in the first instance arise from the crowding itself, but from certain deeply seated circumstances of organic life, one of which is that more material is habitually acquired and incorporated during the life of an individual, whether animal or plant, than has been fully used up when its death supervenes. The defunct body remains after death, whether it be that of a man, a lower animal, or a plant. The existence of dead organic material is a constant witness to this far-

reaching fact, and so it has been throughout the ages. The substances of the body after death may undergo various steps of ulterior use by organisms usually lower in the scale. They all end in the restitution of those organic substances to their inorganic sources. A second circumstance, of recurrent rather than of final importance, is the excretion of matter not fully decomposed. The animal excreta constitute a formidable factor in the problem, while plants also take their share, and most markedly in the autumnal leaf-fall.

It is the herding of human beings and other organisms together upon a limited area of ground, all taking part in, but not completing, that process of restitution which brings with it the imperative need for sanitation. The production of effete matter is so rapid on the crowded site that it cannot be balanced by complete destruction through the ordinary processes of Nature, for they are too slow. They must be speeded up artificially. This is the real office of a sanitary department scientifically conducted. But in such activities, however largely they may bulk in the modern life of crowded cities, we shall see that there is nothing essentially new in Nature, and that officers of health are on a last analysis acting only as Nature's accelerators. They alter the conditions of decay, not its essence. The rapid removal of the by-products of life which they organise makes the crowded life of cities not only possible, but even tolerable, and in point of fact sanitary. What, then, are the sanitary methods of Nature that may be sufficient for the healthy life of a sparse population, but in crowded areas need to be thus speeded up ?

The carbon-cycle, upon which all organic life depends, consists on the one hand of constructive or anabolic changes, and on the other of destructive or katabolic changes of material. The constructive side is represented by the activities of the green plant-cell under sunlight resulting commonly, as we have seen, in the appearance of starch as the first visible product. Closely related to this is the further process by which the carbohydrate thus gained is worked up into protein-material, while oils may play their part, often replacing carbohydrates physiologically as a form of storage. These three proximate principles, proteins, carbohydrates, and oils, together with certain salts, build up the organic structure of the bodies of animals and plants. They may be held as representing material which has been gained in the constructive phase of the carbon-cycle. Such construction is essentially a process of de-oxidation, and, on a general balance, free oxygen is given off as the result. But in the other phases of the cycle we may figure the whole remainder of organic life as playing in the opposite direction, viz. of destruction. The material gained by photo-synthesis is gradually parted with. By successive steps involving oxidation it may be restored to the original inorganic sources, while carbon-dioxide is given off, and the organism in which such changes occur is said to respire. The several steps of change may be held as equivalent to a delayed process of combustion. In ordinary combustion carbon-dioxide is produced, and its production may be held as tangible evidence of the rapid restitution of the material burned to its original sources—water, carbon-dioxide, and ash. So also with the slower restitution involved in Life. Living

animals and plants respire, giving off carbon-dioxide, which is the sign of a slow physiological combustion. The amount of the gas given off may be held as a measure of those katabolic changes, by which organic material is degraded step by step. Whether by fire or by the chemical changes attending life, the combined carbon is restored to the atmosphere from which it was originally drawn.

All the incidents of decay and putrescence that make sanitary measures necessary play in this downward scale. The active agency that brings such changes about is Life itself, supported by materials used at second-hand. Organic substances, whether derived from the bodies of plants or of animals, are used as a basis for the activities of other living things, whether animals or plants. These feed upon those materials, and derive their own motor-power of Life by degrading them ever one step further towards complete restitution. In the broadest sense the whole Animal Kingdom may be held as taking an active part in this downward katabolic trend. The material gained originally from the green plant may be handed on from one animal to another through chains of carnivorous feeding, with loss of its total amount and change of its quality at each successive step. But it is the colourless plants, such as filamentous Fungi and Bacteria, that enter more directly into those changes which make sanitation necessary, and demand the foresight of a municipality. These organisms, and more especially the Bacteria, take their part in the later steps of the degradation of organic matter, such as the refuse of a large town encourages. Each of them, following its own habit of nutrition, acts normally at its own pace

in breaking down organic matter into simpler compounds.

In open Nature the accumulation of effete material is not as a rule great or rapid, and the methods and speed of their decomposition through the agency of lower organisms are such that, compared with the conditions in towns, little harm or inconvenience comes to the country man, dwelling as he does in the midst of such changes. It is only rarely that his attention is drawn to the fact of decomposition, as, for instance, where masses of dead seaweed have accumulated on the shore after a storm, or in the presence of the dead body of one of the larger animals; or, again, where the well that he drinks from is fouled. Man is indeed hardly aware how actively in the open country progressive destruction of organic matter is being carried out by flies, beetles, and ants, worms and protozoa; or by saprophytic Fungi and Bacteria. Yet every rich humus soil is alive with these and other organisms, which are acting all the time, though slowly and inoffensively, as agents of restitution of organic matter to its inorganic sources. Nature is, in fact, her own scavenger and sanitary authority so long as the conditions are themselves natural. Fungi, Bacteria, and Protozoa are her chief organic " destructors," and they work by methods of slow combustion that are sufficient for her normal needs.

The growth and multiplication of the organisms which thus act as scavengers may be illustrated by common examples which are apt to appear on refuse materials in towns. If soaked bread, over-ripe soft fruit, or horse-dung be kept in a close atmosphere, in a day or two a flocculent growth of Moulds will probably

appear, showing that the spores of representatives of the *Mucor* family were already present (Fig. 146). These Moulds are colourless saprophytes, and they
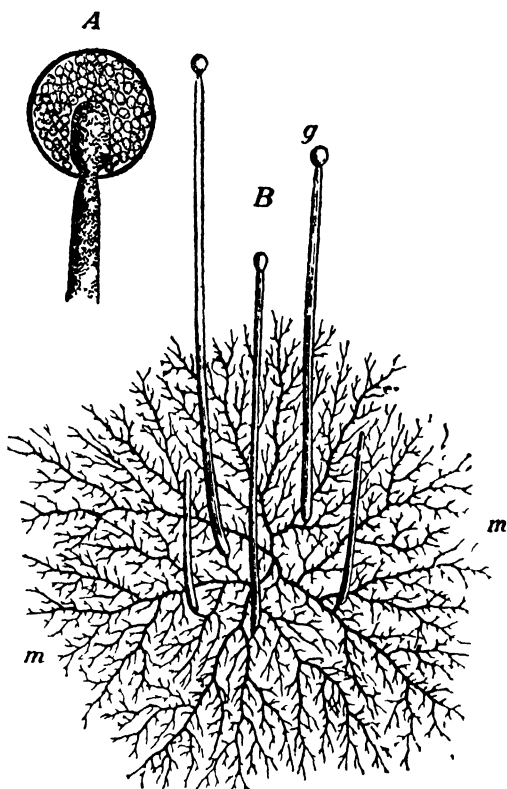
FIG 146   *B*   a young plant of *Mucor* showing the mycelium of finely branched hyphæ (*m*) and fruiting branches (*g*) rising upright from it   *A* a single mature sporangium more highly magnified, containing spores or brood buds   (After Brefeld)

work up the organic material on which they grow into the substance of their coarse filaments.   These bear sporangia in large numbers, each containing many spores, which are scattered in the presence of water (Fig. 147).   They thus spread rapidly where moisture is plentiful.   The family is a very large one, and one

or another of the *Mucors* is capable of growing on almost any moist organic medium. Together with
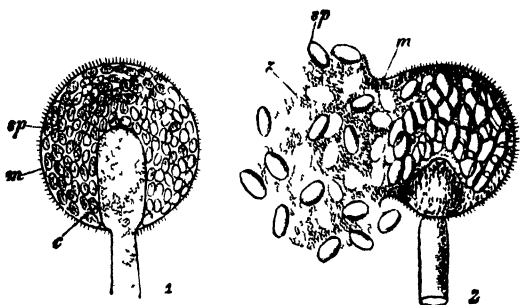
FIG 147 - 1 a mature sporangium of *Mucor* as seen in section
c columella, m—wall of sporangium, within are the spores or
brood-buds (*sp*) 2 a ripe sporangium bursting the wall (*m*)
bursts, and the mucilage in which the spores are embedded swells on
access of water (From Strasburger) (22), 2,00)

the Saprolegniae, which live mostly in water, they appear as active agents in the degradation process, where there is plenty of moisture.

If, however, bread, leather, jam, or some such organic medium be kept relatively dry, but in a confined atmosphere, various Moulds of a different class will be liable to appear upon it, of which the commonest is *Penicillium* (Fig. 148). This plant when mature looks like fine blue-green velvet, and it may cover the whole surface of the medium in a few days. Its name is derived from the very minute brush-like branches, which bear innumerable spores in delicate chains. Many millions of these spores may be produced on a square inch of surface, and they are spread like finest dust by the slightest breath of air. Little wonder, then, that such Moulds are common, and that they should turn up, wherever the conditions are favourable, upon waste household refuse if left long enough. *Penicillium* may be held as an example of those saprophytic Fungi which flourish on any fairly dry

organic rubbish if kept in a confined space, such as a dust-bin.

Filamentous Fungi, like those just described, share undoubtedly in the degradation of dead organic material; but a greater part is performed by the Bacteria. Under natural conditions these various saprophytic organisms live together in any mass of organic refuse. It is only by making pure cultures
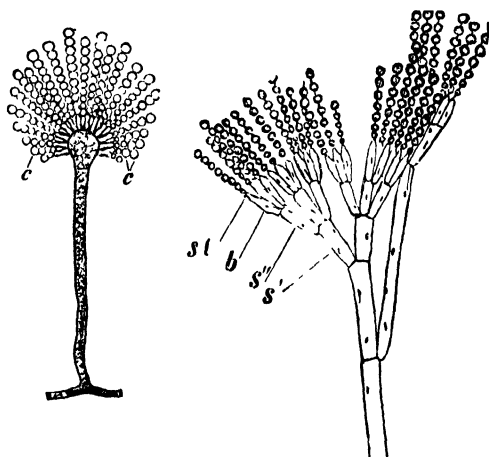
FIG. 148.—FILAMENTS OF TWO COMMON MOULDS, forming their conidia or spores. To the left is *Aspergillus*, with its mop-like heads; to the right is *Penicillium*, with brush-like branches, each bearing a chain of spores, very easily detached by even a slight breath of wind. (After Strasburger.)

of them that a real knowledge can be gained of what each does, and the exact conditions under which it flourishes. But facts of importance may be learned from familiar objects, such as haystacks or manure-heaps. In these, though filamentous Fungi are undoubtedly present, Bacteria take the most active part in the changes that occur. One very prominent result is a rise in temperature. The farmer tests this by thrusting his hand into his newly made hay-stack, and normally finds it warm, but not too hot.

He then knows that the process of " sweating " is progressing as it should. The organic mass, air-dry when stacked, contains sufficient moisture, in which sugar and other substances are dissolved, to favour a moderate development of various Fungi and Bacteria within it. But if the hay has been stacked too wet they are apt to develop too freely, and to heat the stack even to the point of ominous discoloration of its centre. In the normal stack there is moderately active chemical change with evolution of heat—in fact, a partial slow combustion. The same holds for the ordinary hotbed of the gardener. He lays his frame on the top of a mass of ripening farmyard manure, in which the chemical changes wrought by saprophytic activity raise the temperature and force on his seedlings. The same may happen in any midden of a town, with like results as to temperature ; but here the changes are combined with the escape of noxious gases, produced especially by putrefactive germs, which make the heap insanitary and its removal imperative.

The Hay Bacillus, which is an active agent in sweating haystacks but dormant in fully seasoned hay, may be taken as a suitable example of a strongly aerobic saprophyte ; that is, one which develops in presence of free oxygen. To this it would have access in the porous newly made hay ; but as the stack settles the mass becomes more compact and the matured hay cools, while the Bacilli become dormant. From this state they may always be aroused by suitable conditions. Rapidity of multiplication is one of the leading features of bacterial life. The small size of these organisms and their rapid multiplication lead to their astonishing ubiquity, and

these facts account for the sudden effects they may induce in any substratum on which they grow. Many are like the Hay Bacillus aerobic, but others flourish in the absence of oxygen. In particular, the Bacteria which cause putrefaction of proteins are anaerobic. But both types may be active in near proximity to one another, the aerobic Bacteria at the exposed surface and the anaerobic internally in any mass of decaying matter. Such are the agents employed by Nature to do her scavenging.

Primitive man, to whom time and space were not so pressing as they are to us, no doubt depended wholly but unconsciously upon these sanitary agents of Nature, and was satisfied with their deliberate action. But in crowded town life their effect is too slow to remove the accumulations. As urban life extended, primitive methods allowed the noisome ash-heap, with its occasional clearance into the open country. This finds its modern correlative in the daily visit of the dust cart, and the delivery of dry refuse at the destructor. Here rapid combustion replaces the slow steps of decay of organic material, while the final result is virtually the same.

A more serious problem arose, however, with waterborne refuse included under the comprehensive word sewage. Such water-carriage was well known in ancient Rome, as witnessed by her Cloaca Maxima. In our own towns it became a new and an urgent problem as a consequence of the improved water supply. The mere mechanical removal of waterborne organic refuse was the first care, and streams and reservoirs that received it were left to solve their own problem of sanitation. Bacterial action slowly pursued its natural course unaided, with offensive

results that will long be remembered. This was in recent years the condition of many large towns. But in later years sanitary science has harnessed the Bacteria, and has brought them into service. By offering to them, whether their action be aerobic or anaerobic, the best opportunities of quick and effective action, the bacteriolysis of sewage (that is, the bacterial decomposition of its organic burden) is now conducted by methods that need no longer be a public nuisance. The steps of change may be complicated, and the intermediate products far from uniform, but they all tend in the direction of those primary food-materials, viz. carbon-dioxide, water, and salts, which were in the first instance built by constructive metabolism into the body of the green plant.

For the living individual, high or low, great or small, *the physiological* drama ends with *death.* But for *the community* the problem goes further. In open Nature the normal agents of decay act efficiently though slowly in the forest and field or on the sea-shore. But to secure the public health in crowded towns the final return of all organic materials to their inorganic sources must be done more quickly. Fire or saprophytic action under proper control must take the place of casual putrefaction. In carrying this out sanitary science has not ventured upon any departure in principle from Nature's methods of dealing with waste material. What it has done is to adapt those methods to the special needs of overcrowded and sedentary populations.

CHAPTER XXIX

MAN'S DEPENDENCE ON VEGETATION

HUXLEY in his classical essay on *Man's Place in Nature* treated his theme from the evolutionary point of view. Man's place was there defined in its relation to the Animal Kingdom. But Man may also be regarded as an item in the whole sphere of living things, as distinct from the non-living, and in particular the attempt has here been made to trace into some detail his ultimate dependence on the Vegetable Kingdom. Considering this in point of time, we find that he was a relatively late comer upon the scene. However little we may really know about the dawn of life, we are safe in asserting that Man's entry on the stage was made after all the main evolutionary lines of both the kingdoms of Organic Nature were already in being. He has established himself firmly as a dependant in a thousand ways upon organisms of earlier evolution than himself.

Primitive Man, appearing thus as an innovation among older types of life, supported himself partly upon the produce of the chase, partly by gathering also such fruits and other plant-products as came readily to hand. But as his life became more complex, and his requirements expanded, he has brought

the products of plants in ever higher degree into use, and has become more and more dependent upon them for his food, his habitations, his clothing, his curative drugs, his arts, and his luxuries. All the refinements of his life rest on derivative steps more or less removed from the green, photo-synthetic plant-cell. But, conversely, Man has reacted ever more and more upon the primeval vegetation. His hand is evident in any settled country. In accordance with his use and convenience he has disturbed the balance of organic life, moulding or even destroying the vegetation that was there before, and substituting for it plants that meet his varying needs. Sometimes he has elicited from Nature herself, by crossing, cultivation, and selection, things that are actually new. Thus there are two aspects of " Man's place in Nature " viewed in this broader sense : first, his own condition of physiological and material dependence ; and secondly, the influence which he has exercised in modifying natural products so as to serve his own ends.

We have seen in how many ways Man is dependent upon the Vegetable Kingdom for his basic supplies. But the question may still be asked whether photosynthesis in the green cell is the prime source of all vegetable products. If the analysis of their origin be continued to the very end, do we always arrive at the green plant-cell ? or is there any other source of organically combined carbon which may contribute to our well-being ? In particular, are any plants known to be able to construct new organic material in the absence of chlorophyll ? For all practical purposes photo-synthesis may be held to be the uniform source. But still it is known that certain Nitrifying Bacteria can form small amounts of organic substances

from carbonates and ammonia-salts. In suitable culture-solutions it has been shown that nitrous and nitric Bacteria can assimilate sufficient carbon from carbonates to supply what they require for the construction of their own cells. This they can do in the dark, and naturally in the absence of chlorophyll. But it is most improbable that this constructive process can be held as taking any appreciable part in the general supply. The fact that such power exists is in itself interesting, and illustrates again the extraordinary powers of Bacteria. But it cannot be held as materially affecting the general thesis.

For all practical purposes then the fact of Man's dependence, either directly or indirectly, upon the green photo-synthetic cell may be accepted as the starting point of our whole discussion. It has been shown how in respect of food, of clothing, of timber and cordage, and such-like primary supplies, its direct or indirect products are essential not only for his well-being but for his actual existence. The provision of these necessaries, as regarded in bulk or analysed in percentages, has chiefly engaged our attention. Hitherto less note has been taken of those secondary products which, though often present in very small quantity, play nevertheless an essential part in the life of Man. One example has, however, been seen in the " vitamins," those bodies which, though present in so minute a proportion as to be inappreciable in an analysis, are still of vital importance in relation to nutrition. They appear to be acquired in the first instance by the green plant-cell, though they may also be present in other parts of the plant. They may be absorbed as such into the animal body, and so find their way into the human body, through such animal

products as butter, or yolks of eggs, or cod liver oil.
But their actual origin is constantly traced to vege-
table sources.   The foods that supply these bodies
best are green garden vegetables, which should be as
fresh as possible.   Most people prefer fresh viands
when they can get them.   The proved absence of
active vitamins from dried vegetables, and usually
also from preserved foods, gives a physiological
justification for this healthy taste.

A feature too often neglected is the flavour of food,
which again depends upon substances present in very
small quantity.   Physicians understand the impor-
tance of it as an aid to digestion and healthy assimi-
lation.   But it is not always realised how often the
flavour that attracts and stimulates the appetite owes
its origin to the early stages of katabolic change.   The
aroma and flavour of newly baked bread arise chiefly
from bye-products of the activity of the fermenting
yeast that acts upon the materials of the dough.
The flavours of butter and of cheese depend largely
upon the presence and activity of specific microbes,
living under control in the cleanly making of them.
The qualities of well-hung mutton, and of venison and
other game are developed only with keeping.   More-
over, it is remarkable how almost every race of men,
civilised or not, indulges in some strongly flavoured
food which owes its quality to incipient decay.   While
we speak with horror of the over-kept eggs of the
Chinaman, we do not hesitate to stimulate our own
digestion at the end of dinner with a morsel of cheese
fully " ripened " through the katabolic action of Fungi
and Bacteria.   It would not be wise to examine too
closely into all the vagaries of epicurism from this
point of view.   But many of them depend for their

attraction upon the flavours following from the initial stages of decay.

A more pleasing branch of the subject relates to wines, so intimately connected with Man's history and imagination. Though the chemistry of the maturing of fine wine is obscure, its whole history from the parent grape to the moment of perfection in the decanter, is one of katabolic change. That change is believed to begin even while the fully ripened grapes are still hanging on the vine, and one point in the skill displayed in the vintage lies in the judgment of that latest moment when the juice should be crushed out of them. The germs of fermentation, already present on the ripe grapes, then break down the sugar contained in the expressed juice, forming alcohol and carbonic acid ; but at the same time other products appear also, though in small amounts, such as higher alcohols and ethers, and other organic bodies. These come into greater prominence with the maturing of the wine, and particularly with the deposit of the " crust." The character of the growth, and specifically of the vintage, then emerges in full perfection. When the bottle of the mature wine is to be used it is customary to warm it to the temperature of the room where it is to be drunk. The reason for this is to secure an increased vapour-tension of these volatile bodies, and so to give them their perfect effect. When the connoisseur eats nuts or olives he thereby deposits a thin film of oil over the receptive surfaces of the palate : he knows by experience that fixed oils are highly absorbent of aromatic substances.

This fact is made use of in the extraction of scents, which may be held, like the flavours of wines, to be katabolic products. Both the one and the other,

though present in exceedingly small quantity, open whole vistas of the aesthetic, but also at times of the tragic side of Man's life.   The method of " enfleurage " is often employed to extract the scent of violets and other flowers.   Wooden frames, each containing a sheet of glass spread with a thin film of refined fat, are covered repeatedly with fresh flowers.   As the perfume of the first layer is exhausted it is replaced successively by fresh layers, till the fat is saturated with the volatile perfume, which it absorbs.   This gives a strongly scented pomade, from which, if required, the scent can be extracted.   Oil of roses is, however, usually obtained by distilling the petals in water, when the oil collects on the surface of the distillate.   It is stated that five to six thousand kilogrammes of roses are required to produce one kilogramme of the oil : hence the cost of it, which is balanced by its persistent and pervading scent.   Such instances as these may serve to show how small an actual quantity of these katabolic products known as scents is needed to produce their aesthetic effect.

It is the same with many drugs, so varied in their action, at times so beneficent though, as sedatives, stimulants and even poisons, so terrible in their power. Many of these fall into the class of the alkaloids, which are bodies naturally formed in plants, as the result of breaking down of nitrogenous substances, such as proteins.   They are themselves nitrogenous bodies, but may probably be ranked as secretions, which are of no further use to the plant.   Quinine is a good example, which is extracted from the bark of various species of the Peruvian genus, *Cinchona*, now introduced and widely cultivated in the East.   It is a common characteristic of the alkaloids that the active

principle is present in small quantity, and often localised in certain plant tissues, while small doses often produce marked physiological effects. They are products peculiar to certain families of plants, such as the Nightshades, Legumes, and Poppies, while they are entirely absent from others, such as Cresses and Roses, and the Monocotyledons generally.

Vegetable dyes and pigments, so closely related to the arts and manufactures, are also degradation products: for instance, the whole range of aniline colours, which are derived from tar, and ultimately from coal. A striking feature of these katabolic bodies is that the effect, whether toxic or aesthetic, which they produce appears frequently to be so great, and out of all proportion to the quantities used. In this they differ broadly from the ordinary food-stuffs.

No plant product has leaped so suddenly into the front rank as a crop, or commanded so lively a market, as Rubber. If an earlier period may deserve to be called the age of Steel, surely the present is the age of Rubber. The demand has led men to ransack the world for the highest supply of the best quality. But as a matter of fact it is the product of relatively few families of plants, and they are widely distributed, both systematically and geographically. Rubber is a substance used in bulk, and valued for its peculiar physical properties, while it is curiously inert chemically. It is a hydrocarbon or a mixture of them; it is certainly a degradation product of the plant, and probably a secretion having no further physiological value. Its increased production has during the last half-century accompanied its extended application in science and in engineering. One of its drawbacks—

which, however, keeps the market active—is its rapid loss of quality when exposed to the air.

One of the chief sources of Rubber is the family of the Apocynaceae (Periwinkles), from which the African climber *Landolphia* yields a supply collected from the forest by native labour. But clearly the wild sources will not be sufficient for modern needs, while climbers are unsuited for growing as a commercial crop. The market of the present day looks for its chief supply of Rubber to *Hevea*, or, as it was once called, *Siphonia*, a Brazilian tree now planted over immense areas of the tropics, and especially in the Malayan region. It has the advantage of yielding a continual crop of juice, obtained by successive tappings. The produce of this genus has far outstripped that of other plants, and particularly that of the Eastern *Ficus elastica*, which, however, still retains its old name of the India Rubber Tree. It is unnecessary to particularise the modern uses of Rubber. It suffices merely to mention the motor industry. A great extension of the use of Rubber sprang from the discovery in 1839 that it could be " vulcanised." By its combination with about three per cent. of sulphur the toughness and elasticity of Rubber are increased, while it becomes less absorbent for gases and more resistant to solvents. If, however, the sulphur be increased to fifty per cent. the result is ebonite, which is hard enough to be turned in a lathe and polished. The use of this for electric insulation is very extensive.

In the background of all those industries which turn upon products of vegetable katabolism there moves the shadow of synthetic chemistry ; that is, the possibility of the artificial production of the desired substances in the laboratory. In many

markets this is more than a shadow, as witness Vanillin, that replaces the natural aroma of the Vanilla fruit ; Alizarine, that replaces the natural Madder ; Indigo, and even artificial Rubber itself. But sometimes, as in the artificial production of precious stones, the cost of the chemical synthesis is greater than that of supplying the natural article, while in the case of Rubber the physical features upon which the use of Rubber depends are imperfectly presented by the synthetic product. Still, the degree of success already attained in the laboratory shows Man partially superseding Nature by skill and science. Nevertheless, he is very far from being able to live free from Nature's supplies, least of all from those more directly arising through the activity of the green photo-synthetic cell. We are told that it has now been possible for the chemist to construct glucose in his laboratory from the atmosphere, with the aid of ultra-violet rays. But even though this may prove true in fact, such synthesis could hardly supersede the cheap methods of photo-synthesis by the plant in the field or the forest. It is highly improbable that it will ever prove to be an economic proposition. It is still more improbable that such products would satisfy the palate of the populace, while we may be sure that the epicure would for ever remain critical of and unconvinced by any substitutionary food artificially prepared.

CHAPTER XXX

MAN'S INFLUENCE ON VEGETATION

MAN is said to be master of his fate. But this can only be true within limits, and in particular those that are physical and physiological. Subject to such checks, it is open to him to mould his environment to his wishes. In any fully populated country of old settlement his influence on the landscape is plainly seen. The first changes from a primeval state of Nature to the settled home of Man are chiefly destructive. This will have been so in the past, as it certainly is at the present day. Such changes may be seen in rapid progress in any of the dependencies of the Empire, while the result of old settlement appears in any average landscape of the Mother Country. The initial clearance of ancient forest, or the breaking up of old sward, are the most striking tokens of a profound upsetting of that balanced order that characterises intact organic Nature. Before the coming of civilised Man something like a compromise, most delicately poised between competing organisms, had been attained as a result of their striving against circumstances, and against one another. The balance so frequently struck between woodland and grassland described in

a previous chapter is a marked example of it, though the same may work down under analysis also to species, and even to individuals. Man enters upon this self-adjusted scene with axe and fire, or with ploughshare and draining tools, and rudely disturbs the balance. If the country carry forest the trees are felled, not for timber so much as for clearance. But it is not only the trees themselves that are destroyed. The smaller plants of the forest that can flourish only in the deepest shade, or perched perhaps high among the tree tops, share in the general ruin. Only those who have studied primeval forest-life on the spot, and have seen it broken up for planting Tea, Coffee, Cinchona, or Rubber, can realise the tragedy of such destruction. It is the same on a smaller scale of vegetation with prairies and grasslands opened by the plough for cultivation. Such changes are like the wiping out of some old and settled civilisation, never to be restored exactly as it was before ; because the history that led up to it can never be exactly repeated. In place of the romantic balance of a thousand different plants resulting from an age-long struggle, Man substitutes cultivation and the prosaic uniformity of the plantation. This is what, in the language of a company prospectus, is called " developing the country."

Native races also make forest-clearings, but on a smaller scale than the white man, and their tenure of any given plot is often brief. In Ceylon there is a regular method of native cultivation called the chena-system. A stretch of ground is cleared, and it is worked until the soil is exhausted. It is then allowed to relapse into forest, and the cultivators move on. But it is not the primitive forest that grows up on

the deserted plot. *Alien weeds and other intruders*
find their place, so that, though the new growth may
be dense, the old cultivation will still leave its traces
behind in the altered constitution of the forest.

Unforeseen consequences often follow on settlement,
producing destructive changes. The chief cause is fire,
of which the railways and careless camping are the
fertile sources. It is stated that ten million acres of
forest have been so destroyed within the last five
years in Canada alone. A peculiar interest attaches,
however, to those changes in a flora that are of bio-
logical origin. For instance, goats were introduced
into St. Helena, where there was originally a most
characteristic flora. They grazed down everything,
so that many of the peculiar plants of the island are
now best known in old herbaria. Darwin remarked
(*Origin*, chapter xiii.) that there is reason to believe
that in St. Helena the naturalised plants and animals
have nearly or quite exterminated many native pro-
ductions ; and he passes on to the general reflection
that Man has unintentionally stocked oceanic islands
far more fully and perfectly than did Nature. The
success of the intruders brought by Man is sometimes
phenomenal, as though the plants luxuriated in their
new milieu. Darwin describes how the Cardoon
Thistle, introduced at the time of the first occupation
of certain districts of central South America, had
seized an area several hundred miles square to the
exclusion of native plants. The West Indian *Lantana*,
introduced as a garden plant into Ceylon, has been
widely spread by birds eating its berries, and distri-
buting the seeds ; it is now a characteristic feature
of deserted plantation-ground, holding its own against
weaker native competitors. A striking experience in

Britain followed the introduction in the last century of the Canadian water weed (*Elodea*) from the American Continent. Only the female plant was brought over, so that it propagates not by seed but vegetatively. Nevertheless, it has spread throughout the canals and streams of the country so as to be actually an impediment to water-traffic. Such examples show how Man, unwittingly or by sheer carelessness, produces widespread changes in the vegetation of the world. His very weeds follow him as the " white man's footsteps."

On the other hand, vegetation may at times make inroads upon the works of Man. The buildings of a decayed civilisation once derelict may soon be merged in forest. For instance, the remains now being opened up in Central America : the ancient City of Annurhapura, in Ceylon ; and of Zimbabwe, in Eastern Africa ; or sundry temples in India or Java. The forest growth submerges like a flood these works of Man. Thus though at one spot vegetation may go down before the planter, at another it is seen to overwhelm Man's ancient settlements. But these are exceptional incidents. The balance all over is strongly against the primitive vegetation. Taking a general synopsis of the world, the ancient floras, so rich and varied in their constitution, are suffering rapid annihilation. They give way before that dead uniformity of species that is seen in modern cultivation. Natural selection, with its consequent survival of the fittest yet established on the particular site, gives way before human selection, which secures by husbandry the survival of those plants that prove the most remunerative in the market. These vegetable helots that supplant the old aristocracy are mostly introduced

aliens. Truly Man's economic development of a
country deprives it of much of its natural romance.

There is, however, another side to the picture.
Man's influence is also constructive and utilitarian in
its aim. Plants long cultivated, or it may be wild
plants selected for some specific use, are comprised
within the circle of these new elect. Their place there
is secured for them by various features : for instance
(i) by the possession of special qualities of form, colour,
aroma, or flavour in flowers or fruits ; (ii) by the rapid
production of garden foodstuff, or timber, or fibre in
bulk ; (iii) by the production of a high percentage of
some specific content in the tissues ; or (iv) by their
power of resistance to extremes of climate or to disease.
Some of them remain little altered from the wild
species, for instance, Tea, Coffee, or Tobacco. But
Man has been able to modify and improve others by
long cultivation, by selection, by acclimatisation, and
by hybridisation of species and varieties, and to re-
distribute the stocks, preserving the special qualities
he desires. These stocks become established under
his care as more or less standardised exponents of his
skill in shaping natural objects to an ideal.

The flower and fruit gardens provide striking illus-
trations in which, with relative uniformity of the vege-
tative system, a wide variety is attained in the pro-
pagative organs. The breeder has concentrated his
skilled efforts on the propagative system, and the
results are evident in the quality of the flowers and
the fruit displayed at any horticultural show. They
are often very different from the original parentage.
The converse of this appears in the vegetable plot.
Age-long cultivation of plants of kitchen-value has
diverted them into lines far removed from the primitive

wild species.   The divergent types traceable in origin from the wild *Brassica oleracea* are the most familiar examples, showing in the drum-head Cabbage, Brussels Sprouts, Curly Kale, and Kohl Rabi, how Man has impressed his own requirements upon their vegetative system.   But their floral characters, which in this instance are of no immediate interest to him except as producers of the requisite seeds, remain virtually uniform, in near likeness to those of the primitive parentage.   So it is with other garden vegetables such as Radish, Beet, Carrot, and Asparagus, which all retain their floral characters essentially intact.   This antithesis between the denizens respectively of the flower-and-fruit garden and those of the kitchen-plots is itself a most striking illustration of the power possessed by the plant-breeder.   It shows how it lies in his hand to modify to his will, and in great measure independently of one another, either the vegetative system of plants or their propagative system.

No effects are more striking than those produced by hybridisation, instances of which are on record for most of the prominent garden products.   A good case in point is seen in the stock of Begonias based upon parentage from *Begonia socotrana,* an endemic species from the island of Socotra.   Tubers of it were brought home by its discoverer, Sir Isaac Bayley Balfour, in 1880.   The plants raised from these tubers, which are characterised by peltate leaves and pink flowers, have been the parents of untold hybrids now in cultivation, many of which share the peltate leaves and pink flowers of the original stock.   In particular the cross of *B. socotrana* (male) with *B. dregei* (female) has given one of the most free-flowering of decorative plants.

Hybridisation is now no longer the haphazard game of chance that it used once to be. A recognition of the fact of the segregation of heritable characters, according to the principles first discovered by Mendel, has led to more definite design in bringing the desired characters together, and the consequence is enhanced precision in arriving at results. These are still far from being exact, however, in highly cultivated and mixed races ; but we may anticipate that as time goes on the scope and power of experimental hybridisation will steadily increase. As a practical example of what has already been done constructively upon the basis of Mendelian method, we may quote Biffen's experiments, so arranged as to centralise the factors actually desired in Wheat to be grown in Britain for bread-making. High cropping power, resistance to disease, and high content of " gluten," so as to give a good " rising " loaf, are the requisite features. But these had not hitherto been united in a single strain. Professor Biffen, having selected varieties which possessed these several heritable characters, has been able to build up from them by hybridisation a strain of Wheat which combines them all. It has been found to retain those characters in its progeny, and it is thus suited to supply certain ideal requirements. This may be held as the most practical result hitherto attained by experimental hybridisation, and it may have far-reaching effect upon British Wheat-growing.

On the other hand, a careful selection of strains and high cultivation may sometimes suffice to affect the output in high degree. The result may be that markets will be disturbed, and whole industries be developed or destroyed. An illustration is seen in the Sugar-Beet, from which an ever-increasing proportion

of the world-supply of sugar is derived.   The success of the crop will depend largely upon the percentage of sugar which it contains.   In 1880-1890 it is stated that the average percentage of sugar in the Beet was 10·6, but in 1900-1910 it rose to about 15 per cent.   As a consequence of high cultivation and the liberal use of nitrogenous and potash fertilisers, it rose further in 1908-09 to about 18·5 per cent., while in individual roots as much as 27 per cent. has been recorded.   Such results, for a crop cultivated in those countries where the sugar is to be refined and used, cannot fail to have their effect in competition with the Sugar-Cane grown in the tropics, in which the percentage of cane-sugar is about 20 per cent. of the expressed juice.

An example of the practical effect of selecting the best yielding species or strains, or rather of failure to select the best, may be seen by any visitor to Jamaica, at the Cinchona Plantation in the Blue Mountains. Formerly quinine was largely grown there by the Government.   This station is now derelict.   Its activity was wiped out by the greater success of the Cinchona Plantations in the Eastern tropics, and particularly in Java.   A higher yielding type had there been grown, while the Jamaican establishment had used one of lower yield.   The fall in prices following from a better percentage elsewhere left the alternative of either replanting with a better yielding type, or of closing down ; the Government chose the latter, and now only occasional *Cinchona* trees in the secondary forest remain to show that a flourishing industry once existed there.

As his civilisation advances Man is certainly becoming more and more expert in influencing the

productivity of the soil.   He has access to the vegetation of the whole globe, which gives him the widest possible range of choice of what he will grow.   He establishes the selected species or varieties in new and favourable sites, and within limits he can alter their characters to meet his needs.   Moreover, he is beginning to acquire skill in building up, by methodical inter-crossing, strains that retain by inheritance qualities not united before in the individual plant. But hitherto all such activities play within a comparatively narrow sphere.   Physical and physiological limitations are constantly stepping in to restrict his results.   He learns by experience the hard fact that he must not expect to escape from those physiological trammels within which his physical organisation came into existence.   Notwithstanding the degree of his successes, it is ever impressed upon him that he will have to carry on the struggle for that existence through the medium of the Vegetable Kingdom.   He has always been physiologically dependent upon Plants in the first instance for his material supplies, and it is probable that he will remain so as long as the present order of Nature lasts.

The foregoing Essays have necessarily been limited to a survey of the physical interactions that exist between Plants and Man.   Anyone who is content to estimate those relations simply in a material sense will see how deeply Man is indebted to the activities of Plant-Life.   But there is a further point of view of which the adequate treatment would lie beyond the scope of this volume.   Not only is Man's body supported but his mind is elevated by that primal and enduring phase of

terrestrial life. For we owe to Plants, growing in the nursing soil and active in the sunshine from above, intimate presentations of beauty and suggestions of mystery not wholly resolved under the chill light of scientific analysis. From whatever aspect we regard them, the words of Isaiah will yet remind us, "Look unto the rock whence ye are hewn": but his further injunction, "Lift up your eyes to the heavens," may open for us a wider vision.

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